PB84-211143

Logan Wash Field Treatability Studies of Wastewaters from Oil Shale Retorting Processes

Monsanto Research Corp., Dayton, OH

Prepared for

Industrial Environmental Research Lab.
-Cincinnati, OH

Jun 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-211143

EPA-600/2-84-115
June 1984

LOGAN WASH FIELD TREATABILITY STUDIES OF WASTEWATERS FROM OIL SHALE RETORTING PROCESSES

by

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Contract No. 68-03-2801

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-84-115

2.

3. RECIPIENT'S ACCESSION NO. PB84-211143

4. TITLE AND SUBTITLE
Logan Wash Field Treatability Studies of Wastewaters From Oil Shale Retorting Processes

5. REPORT DATE June 1984

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
B. O. Desai, D. R. Day, and T. E. Ctvrtnicek

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Monsanto Research Corporation
1515 Nicholas Road
Dayton, Ohio 45418

10. PROGRAM ELEMENT NO. DU N104

11. CONTRACT/GRANT NO. 68-03-2801

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Laboratory
Office of Research and Development
Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED Project Report

14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Treatability studies were conducted on retort water and gas condensate wastewater from modified in-situ oil shale retorts to evaluate the effectiveness of selected treatment technologies for removing organic and inorganic contaminants. At retorts operated by Occidental Oil Shale, Inc., at Logan Wash, Colorado, treatability studies were conducted on retort water using filter coalescing, steam stripping, activated sludge treatment (both with and without powdered activated carbon addition), sand filtration, and granular activated carbon adsorption. Retort water had high concentrations of ammonia-nitrogen, total Kjeldahl nitrogen, alkalinity, dissolved organics, phenols, sulfide, total dissolved solids, boron, potassium and sodium. Steam stripping removed ammonia-nitrogen, alkalinity, and sulfide from retort water and organics removal was low. Gas condensate wastewater had high concentrations of ammonia-nitrogen, total Kjeldahl nitrogen, dissolved organics, alkalinity, phenols, sulfide, and pyridine compounds. The overall scheme for the gas condensate treatment removed ammonia-nitrogen, total Kjeldahl nitrogen, alkalinity, sulfide, biochemical oxygen demand, dissolved organic carbon, chemical oxygen demand, and phenols.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Oil Shale Pollution, Fossil Fuels, Oil Shale Wastewater, Steam Stripping, Oil Shale, Wastewater, Synthetic Fuels, Energy		NTIS Terms: 97F Fuel Conver. 97R Energy, Environmental Studies, 99A Analytical Chemistry

18. DISTRIBUTION STATEMENT Release to Public	**19. SECURITY CLASS** *(This Report)* Unclassified	**21. NO. OF PAGES** 185
	20. SECURITY CLASS *(This page)* Unclassified	**22. PRICE**

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

New synthetic fuel processes under development must be characterized prior to commercialization so that pollution control needs are identified and control methods can be integrated with process designs. Shale oil recovery processes are expected to have some unique air, water, and solid waste control requirements. This document describes pilot-scale treatability tests on wastewaters from retort operations at the site of a major oil shale developer.

Further information on the environmental aspects of shale oil processing can be obtained from the IERL-Ci.

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Director
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ABSTRACT

Treatability studies were conducted on retort water and gas condensate wastewater from modified in-situ oil shale retorts to evaluate the effectiveness of selected treatment technologies for removing organic and inorganic contaminants.

At retorts operated by Occidental Oil Shale, Inc., at Logan Wash, Colorado, treatability studies were conducted on retort water using filter coalescing, flocculation/clarification, and steam stripping. Studies also were conducted on gas condensate wastewater using filter coalescing, steam stripping, activated sludge treatment (both with and without powdered activated carbon addition), sand filtration, and granular activated carbon adsorption.

Retort water had high concentrations of ammonia-nitrogen, total Kjeldahl nitrogen, alkalinity, dissolved organics, phenols, sulfide, total dissolved solids, boron, potassium and sodium. Filter coalescing was not effective in further reducing the low concentration of oil and grease in the retort water subjected first to oil/water separation by Occidental. Flocculation/clarification using lime as the chemical conditioning agent was not effective in further reducing the low initial concentration of total suspended solids, or the chlorides, fluorides, and metals at dosages used. Steam stripping removed ammonia-nitrogen, alkalinity, and sulfide from retort water and organics removal was low.

Gas condensate wastewater had high concentrations of ammonia-nitrogen, total Kjeldahl nitrogen, dissolved organics, alkalinity, phenols, sulfide, and pyridine compounds. Filter coalescing was not effective in further reducing the low concentration of oil and grease initially present. Steam stripping successfully removed ammonia-nitrogen, alkalinity, sulfide, phenols, dissolved organic carbon, total Kjeldahl nitrogen and chemical oxygen demand, and it generated wastewater for downstream activated sludge treatment. Organics removal in the stripper was high and varied with the quality of the raw wastewater. Steam was used to try and clean the steam stripper and overhead vapor condensate lines of occasional clogging with partial and short-term success. Conventional activated sludge treatment reduced chemical oxygen demand, soluble biochemical oxygen demand, dissolved organic carbon, and phenols. Despite a long sludge age, nitrification did not occur. Alum was added to enhance settling of the aeration basin overflow sludge. Biological cell growth was very slow. Adding the powdered activated carbon into the aeration basin increased removal of the chemical oxygen demand, dissolved organic carbon, soluble biochemical oxygen demand, and phenols. Sand filtration removed suspended solids from the secondary clarifier effluent and prevented clogging of the downstream adsorption columns. Granular activated carbon adsorption removed organics from conventional activated sludge system effluent. The overall scheme for the gas condensate treatment removed ammonia-nitrogen, total Kjeldahl nitrogen, alkalinity, sulfide, biochemical oxygen demand, dissolved organic carbon, chemical oxygen demand, and phenols.

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ABBREVIATIONS

BOD$_5$ -- biochemical oxygen demand (5 days)
COD -- chemical oxygen demand
DO -- dissolved oxygen
DOC -- dissolved organic carbon
GAC -- granular activated carbon
GC/MS -- gas chromatography/mass spectrometry
G/L -- gas-to-liquid
HRT -- hydraulic retention time
ICP -- inductively coupled plasma optical emission spectroscopy
MIS -- modified *in-situ*
MLSS -- mixed liquor suspended solids
MLVSS -- mixed liquor volatile suspended solids
NH$_3$-N -- ammonia nitrogen
NO$_3$-N -- nitrate nitrogen
PAC -- powdered activated carbon
QA/QC -- quality assurance/quality control
SD -- standard deviation
SRT -- solids retention time
TDS -- total dissolved solids
TKN -- total Kjeldahl nitrogen
TSS -- total suspended solids
VSS -- volatile suspended solids

ACKNOWLEDGEMENTS

Monsanto Research Corporation (MRC) acknowledges the excellent cooperation and support received from personnel of the Occidental Oil Shale, Inc., Logan Wash Operations during the planning and implementation of the field treatability studies described in this report. The technical direction provided by Walter Liberick, Jr., EPA Project Officer, is greatly appreciated.

SECTION 1

INTRODUCTION

Oil shale has been recognized as a substantial energy resource for more than 100 years. Recently, the increasing dependence of the United States on foreign oil supplies, accompanied by rapidly escalating oil prices, has provided incentives for shale oil recovery from deposits in the western United States. Several domestic corporations have begun preliminary process research and development and have acquired the necessary know-how for commercial-scale shale oil production [1].

Despite the benefits of oil shale as an energy resource, wastewaters generated from oil shale processing contain high concentrations of organic and inorganic contaminants. If discharged untreated, these wastewaters could have an adverse impact on the environment. Treatment methods capable of controlling these potentially harmful discharges need to be demonstrated so that adequate controls can be incorporated into full-scale plant designs to assure industry compliance with future standards.

To assess the characteristics and treatability of wastewaters generated from the processing of oil shale, the U.S. Environmental Protection Agency (EPA) contracted with Monsanto Research Corporation (MRC) to conduct a five-phase program having the following objectives:

- Summarize available information concerning oil shale retort wastewater sources and characteristics;

- Identify control technologies that are potentially applicable to treatment of the identified wastewater streams;

- Design pilot-scale units capable of evaluating the applicable technologies at oil shale processing sites;

- Construct the pilot-scale units; and

- Operate the pilot-scale units to develop information on treatment technology performance.

The results of Phases I and II, which were completed in February 1980 and reported earlier [1], comprised:

- A survey of pertinent oil shale retorting processes and water effluents;

- A survey of completed and ongoing research activities in oil shale retort wastewater treatability; and

- Identification of research needs, and development of a research program to meet those needs.

The results of Phases I and II showed that little information existed on the basis of which to evaluate and select potentially applicable technologies for testing, and that additional bench-scale testing and wastewater characterization were warranted. Wastewater characterization and bench-scale treatability studies were thus conducted using samples of the wastewaters available at the time. These studies specifically included:

- Steam stripping, hyperfiltration, and ultrafiltration of Occidental Oil Shale Retort 6 retort water and gas condensate;

- Carbon adsorption batch isotherm and respirometry testing of steam-stripped Occidental Oil Shale Retort 6 retort water and gas condensate;

- Carbon adsorption column testing and activated sludge treatment of steam-stripped Occidental Oil Shale Retort 6 gas condensate;

- Steam stripping of venturi scrubber water collected at the Laramie Energy Technology Center (LETC); and

- Characterization of three gas condensate (Occidental Oil Shale, Inc., Rio Blanco Oil Shale Company, and Development Engineering, Inc.) and four retort water (Occidental Oil Shale, Inc., Rio Blanco Oil Shale Company, Laramie Energy Technology Center, and Geokinetics, Inc.) samples.

The results of these studies, and the information previously collected were used to select the treatment schemes for implementation under Phases III through V. The schemes were presented to EPA in a Work Plan on July 24, 1981 [2] and, after some modification, were approved for implementation. Pilot testing of the schemes commenced on May 5, 1982 at the site operated by the Occidental Oil Shale, Inc. in Logan Wash, Colorado. The tests were completed on August 27, 1982.

This report presents the Logan Wash test program and discusses the test results accomplished. Section 2 summarizes the conclusions derived from the test results. Section 3 describes the Occidental retorting facility, the test equipment, and the Logan Wash test program that was implemented by MRC from May 5 through August 27, 1982. The test results are discussed and summarized in Section 4. Analytical quality assurance/quality control (QA/QC) data are summarized in Section 5.

This report was submitted in partial fulfillment of Contract No. 68-03-2801 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period March 1980 to April 1983. Work was completed May, 1983.

SECTION 2

CONCLUSIONS

2.1 RETORT WATER TESTING

- Retort water has high concentrations of ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), alkalinity, dissolved organics, phenols, sulfide, total dissolved solids (TDS), boron, potassium, and sodium. The retort water tested had an average of 2,200 mg/L ammonia nitrogen; 2,100 mg/L TKN; 14,000 mg/L alkalinity (as $CaCO_3$ to pH 4.5); 1,700 mg/L dissolved organic carbon (DOC); 4,100 mg/L soluble chemical oxygen demand (COD); 2,000 mg/L soluble biochemical oxygen demand (5-day) (BOD_5); 56 mg/L phenols; 90 mg/L sulfide; 14,000 mg/L TDS; 37 mg/L boron; 170 mg/L potassium; 2,900 mg/L sodium; and a pH of 8.8.

- Filter coalescing was not effective in removing the low residual oil and grease content from the retort water. On the average only 6% removal was achieved, primarily owing to its prior removal by Occidental and the resulting level (113 mg/L average) in the retort water.

- Flocculation/clarification treatment of retort water was conducted using lime as the chemical conditioning agent. Testing was conducted at 90, 180, and 270 mg/L lime dosages. This treatment was not effective in removing total suspended solids (TSS), chlorides, fluorides, and metals from the retort water at these dosages. This was primarily because of the low

TSS content of the retort water (59 mg/L average), and because the lime concentrations and pH were not high enough to precipitate metals.

- Steam stripping tests were conducted at gas(steam)-to-liquid (G/L) ratios of 70, 130, 180, 230, and 300 kg/m^3 (0.6, 1.1, 1.5, 1.9, and 2.5 lb/gal). Ammonia, alkalinity, and sulfide could be successfully stripped from the retort water. Greater than 97% of the ammonia nitrogen and 47% of the alkalinity were removed at G/L ratios of 180 kg/m^3 or above (1.5 lb/gal or above). Over 99% of the sulfide was stripped at G/L ratios as low as 70 kg/m^3 (0.6 lb/gal). TKN and phenols removals varied from 71% to 95%, and 27% to 54%, respectively, depending on G/L ratio. The stripper effluent had a pH about one unit higher than that of the feedwater. Organics removal was insignificant.

2.2 GAS CONDENSATE TESTING

- The retort gas condensate had high concentrations of ammonia nitrogen, TKN, alkalinity, dissolved organics, phenols, sulfide, and pyridine compounds. The gas condensate tested had an average of 9,000 mg/L ammonia nitrogen; 6,800 mg/L TKN; 31,000 mg/L alkalinity (as $CaCO_3$ to pH 4.5); 890 mg/L DOC; 2,700 mg/L soluble COD; 800 mg/L soluble BOD_5; 120 mg/L phenols; 72 mg/L sulfide, 100 mg/L pyridine compounds, and a pH of 8.5.

- Filter coalescing was ineffective in removing the low residual oil and grease content of the gas condensate (19 mg/L average). On the average, 28% removal was achieved, adding little to the overall treatment.

- Steam stripping of condensate was conducted at G/L ratios of 60, 120, 150, and 180 kg/m^3 (0.5, 1.0, 1.25, and 1.5 lb/gal). Ammonia nitrogen, alkalinity, sulfide, phenols, COD, DOC, and TKN were successfully stripped from the gas condensate: 99% of ammonia nitrogen and alkalinity were removed at G/L ratios of 120 kg/m^3 (one lb/gal) and above; 99% of the sulfide, 50% of the phenols, and greater than 60% of the organics and TKN were removed at G/L ratios of 60 kg/m^3 (0.5 lb/gal) and above. The stripper effluent had a higher pH than the feed by about one unit at all G/L ratios tested from 60 to 180 kg/m^3 (0.5 to 1.5 lb/gal).

- The steam stripper performed consistently well during the 14 weeks of operation in generating wastewater for downstream activated sludge treatment. At an average G/L ratio of 140 kg/m^3 (1.2 lb/gal), the ammonia nitrogen, TKN, alkalinity, and sulfide removal rates averaged 99%, 96%, 99%, and 97%, respectively. High organics removal (COD >70%, DOC >80%) were obtained during the early period of operation, but gradually these removal rates decreased to 30-40%. This is believed to be due to a change in the quality of the raw wastewater and/or partial clogging of stripper packing; the organics content almost doubled during the later period of operation. The stripper packing clogged up periodically (every 7-10 days) and was partially cleaned by blowing steam through the column. Overhead vapor condensate lines also clogged periodically with ammonium carbonate every 30-45 days and required cleaning with steam.

- The conventional activated sludge system removed an average of 57% of the COD, 91% of the soluble BOD$_5$, 52% of the DOC, and 95% of the phenols. Despite an extended sludge age of 32 days, nitrification did not occur. Due to financial and schedule limitations, and an expected lengthly acclimation period, operation of the activated sludge system for an entire sludge age and under steady-state was not achieved. Data was collected at conditions which represent consistent organics removals and DO uptake rates. Alum addition was required to help settle the sludge in the aeration basin overflow.

- The powdered activated carbon (PAC) activated sludge system, at a PAC dosage of 400 mg/L, removed 70% of the COD, 59% of the DOC, 96% of the soluble BOD_5, and 99% of the phenols. At a PAC dosage of 1,900 mg/L, 86% of the COD, 84% of the DOC, 95% of the soluble BOD_5 and 100% of the phenols were removed.

- Sand filtration was effective in removing suspended solids from the secondary clarifier and prevented clogging of downstream granular activated carbon (GAC) adsorption columns.

- The GAC adsorption treatment was effective in removing organics from conventional filtered activated sludge system effluent. With an empty bed contact time of 22 minutes, the GAC adsorption produced an effluent with a COD <90 mg/L, DOC <26 mg/L, BOD_5 <10 mg/L, and phenols <0.015 for 225 hours.

- GAC adsorption of the stripper effluent with an empty bed contact time of 22 minutes resulted in a COD <50 mg/L, DOC <35 mg/L, BOD_5 <50 mg/L, and phenols <0.005 mg/L for 72 hours.

- The overall gas condensate treatment scheme was effective in removing ammonia nitrogen, TKN, alkalinity, sulfide, BOD_5, DOC, COD, and phenols.

SECTION 3

THE LOGAN WASH TEST PROGRAM

3.1 TEST LOCATION

The test program was implemented at Occidental's Logan Wash test site. Occidental Oil Shale, Inc. (Occidental), a major oil shale developer, purchased this 16 km^2 (4,000 acre) site in 1972 to pursue their interest in shale oil extraction technology development. The site is located on the western slopes of the Rocky Mountains about 16 km (10 mi) northeast of DeBeque, Colorado, and is estimated to contain 0.12 km^3 (750 million barrels) of shale oil in medium-grade deposits. The deposits are 80 m (250 ft) thick and average about 71×10^{-3} m^3 (17 gallons) of oil per tonne (ton) of shale [3].

3.2 OCCIDENTAL'S MIS RETORTING TECHNOLOGY

Occidental Oil Shale, Inc., is involved in the development of modified in-situ (MIS) retorting of oil shale. Starting in 1968, Garrett Research and Development Company, the forerunner of Occidental Research Corporation, started developing this technology through laboratory studies in LaVerne, California, and field tests at Logan Wash near DeBeque, Colorado.

An MIS retort is a fixed-bed chemical reactor constructed within "unbroken" shale rock, (see Figure 1). In the Occidental process rooms or voids are first mined out of the shale strata to define

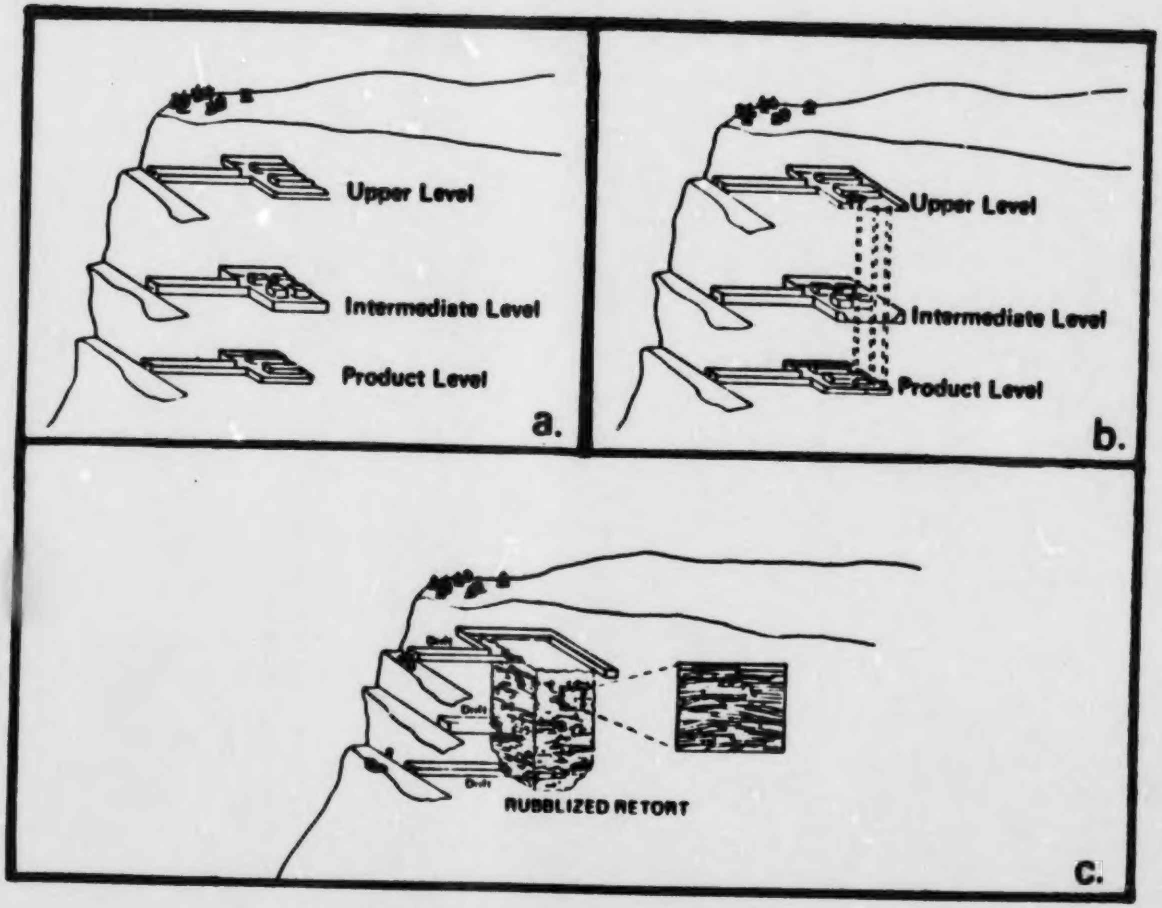

Upper Level
Intermediate Level
Product Level
a.
Upper Level
Intermediate Level
Product Level
b.
Drift
Drift
Drift
RUBBLIZED RETORT
c.

Figure 1. Creating an MIS retort by (a) mining the voids, (b) drilling the blast holes, and (c) fragmenting with explosives.

the retort boundaries. Using explosives placed strategically in holes drilled in the shale between the mined-out voids, the remaining shale is fractured (or rubblized) and expanded into a column of shale with the desired size and void distribution. The mined void defines the ultimate average rubble void and provides for effective flow of process gases and products through the retort. The quantity, placement, and delay pattern of the explosive provide the desired rubble size and void distribution.

After rubblizing, the retort is fitted with means for introducing the retorting gases (air and steam) and withdrawing the liquids and gases produced. The rubble bed is then ready for ignition and processing. Ignition, is accomplished by heating the rubble surface as uniformly as possible to the auto-ignition temperature. At that temperature, residual char and organics in the surface shale react with oxygen in the retorting gases and generate the energy needed to establish and sustain the retorting front.

During retorting, the rubble bed comprises four distinct zones as shown in Figure 2:

(1) A preheating zone in which sensible heat in the spent shale is transferred to the incoming retorting gases;

(2) A combustion zone in which oxygen in the preheated retorting gases reacts with residual char in the retorted shale and generates heat for retorting;

(3) A retorting zone in which the hot gas leaving the combustion zone heats the downstream shale sufficiently to break down the kerogen (carbonaceous portion of shale) into oil, gas, and residual char; and

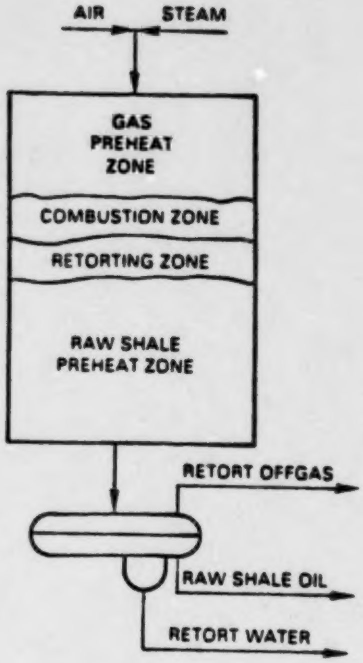

AIR
STEAM
GAS PREHEAT ZONE
COMBUSTION ZONE
RETORTING ZONE
RAW SHALE PREHEAT ZONE
RETORT OFFGAS
RAW SHALE OIL
RETORT WATER

Figure 2. The four zones of an operating MIS retort.

(4) A raw shale preheat zone in which product vapors and liquids are cooled and condensed and the unretorted shale is preheated in preparation for retorting. Simultaneously, condensed liquids, collected in sumps at the bottom of the retort, and the retort off-gas are brought to the surface for further processing.

The Logan Wash test program was implemented during Occidental's burn of Retorts 7 and 8. Prior to Retorts 7 and 8, Occidental has completed six MIS retorts, three of which were of commercial size.

3.3 MIS RETORTS 7 AND 8

Commercial-size Retorts 7 and 8 were prepared for ignition in late 1981 and early 1982 to demonstrate the capability of MIS technology for recovery of 60% of the oil from the shale. Thus, with an average shale grade of 71 x 10^{-3} m^3 per tonne (17 gallons per ton), these two retorts, each 50 m (165 ft) square by 74 m (245 ft) tall, contained approximately 45,000 m^3 (283,000 barrels) of oil. Some 27,000 m^3 (170,000 barrels) of this oil were expected to be recovered: 2,200 m^3 (14,000 barrels) as light oil for use as fuel in the site steam plant and the remainder to be brought to normal shipping standards in a heater treater before shipment off site for testing and further upgrading.

The relative positions of Occidental's Retorts 7 and 8 are shown in Figure 3. Also shown in this figure is retort 8X which was not burned, but rather was designed to evaluate "communication" (through undisturbed shale) between the two adjacent retorts. Retort 7 was ignited on February 1, 1982 and reached a steady burn condition about March 1, 1982. Retort 8 was ignited on December 27, 1981 and also reached a steady burn on March 1, 1982. Thus, by the time the Logan Wash test program began on May 5, both retorts were operating in a steady mode.

3.4 WASTEWATERS GENERATED FROM RETORTS 7 AND 8

Four types of wastewaters were generated from the operation of Retorts 7 and 8: retort water, gas condensate, steam plant blowdown, and mine wastewater. The two wastewater streams, retort water and gas condensate, are generic to oil shale retorting and were the only streams tested in this study.

3.4.1 Retort Water

Retort water is generated during MIS retorting when a portion of the water vapor in the retort off-gas condenses in cooler sections of the retort. This water typically mixes with crude shale oil in the retort and percolates down through the unburned, rubblized

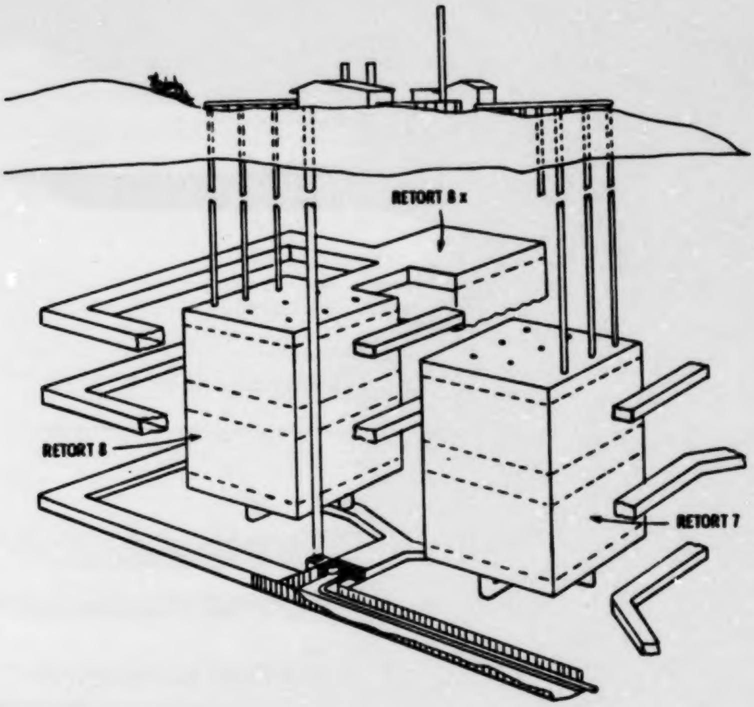


Figure 3. Occidental Oil Shale, Inc. Retorts 7 and 8.

shale. The retort water/oil mixture accumulates in the product collection sump at the retort bottom and is subsequently pumped out and treated to recover the bulk of the shale oil.

Retort waters are heavily contaminated, containing significant concentrations of organics, ammonia, and acid gases (hydrogen sulfide and carbon dioxide). In addition, the intimate contact between this water and the rubblized shale results in leaching of inorganic salts, yielding a substantial concentration of dissolved inorganic solids. Although the volume of retort water produced can vary widely depending upon the amount of injected steam and the extent to which groundwater infiltration into the retort occurs, MIS retorts using steam as diluent gas are reported to produce retort water at a rate of approximately 0.4 m^3 (0.4 barrel) of water per cubic meter (barrel) of product oil [4].

At the Logan Wash site, the oil/water separation equipment for Retorts 7 and 8 was located on a bench on the side of the mountain adjacent to the product collection sump. The oil/ water mixture was pumped out of the retort sumps to the measuring tank (Tank 6) where the crude shale oil and the retort water were separated by passing through several oil/water separation steps. Figure 4 is a schematic diagram of this arrangement. The retort water used in this study was supplied from the measuring tank (Tank 6) at point A in Figure 4. Retorts 7 and 8 retort water production rate over the test period ranged from 670 cm^3/s to 740 cm^3/s (360 barrels per day to 400 barrels per day) as illustrated in Figure 5.

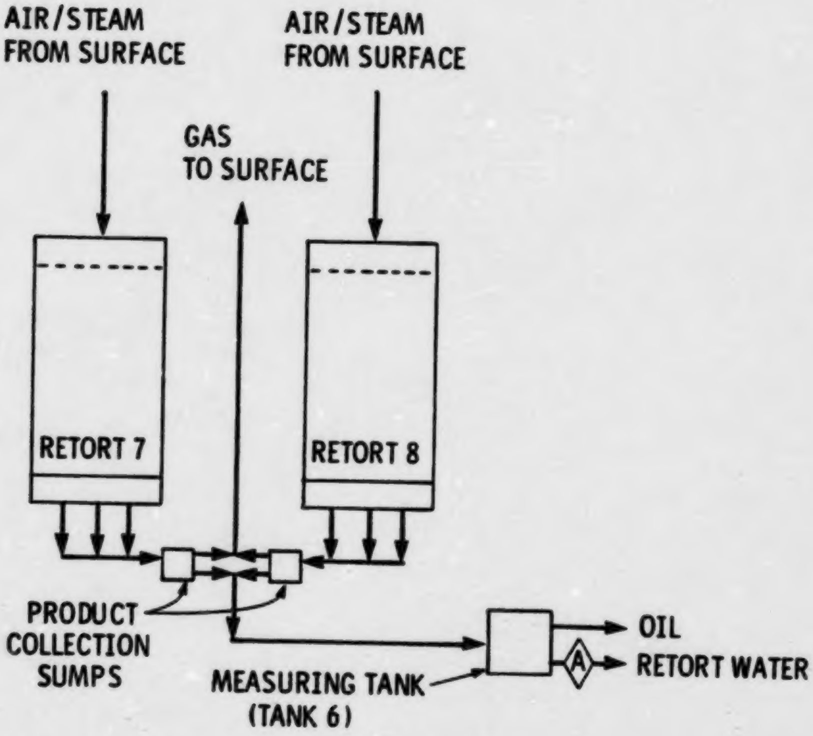

AIR/STEAM FROM SURFACE
AIR/STEAM FROM SURFACE
GAS TO SURFACE
RETORT 7
RETORT 8
PRODUCT COLLECTION SUMPS
MEASURING TANK (TANK 6)
A
OIL
RETORT WATER

Figure 4. Retort water supply point.

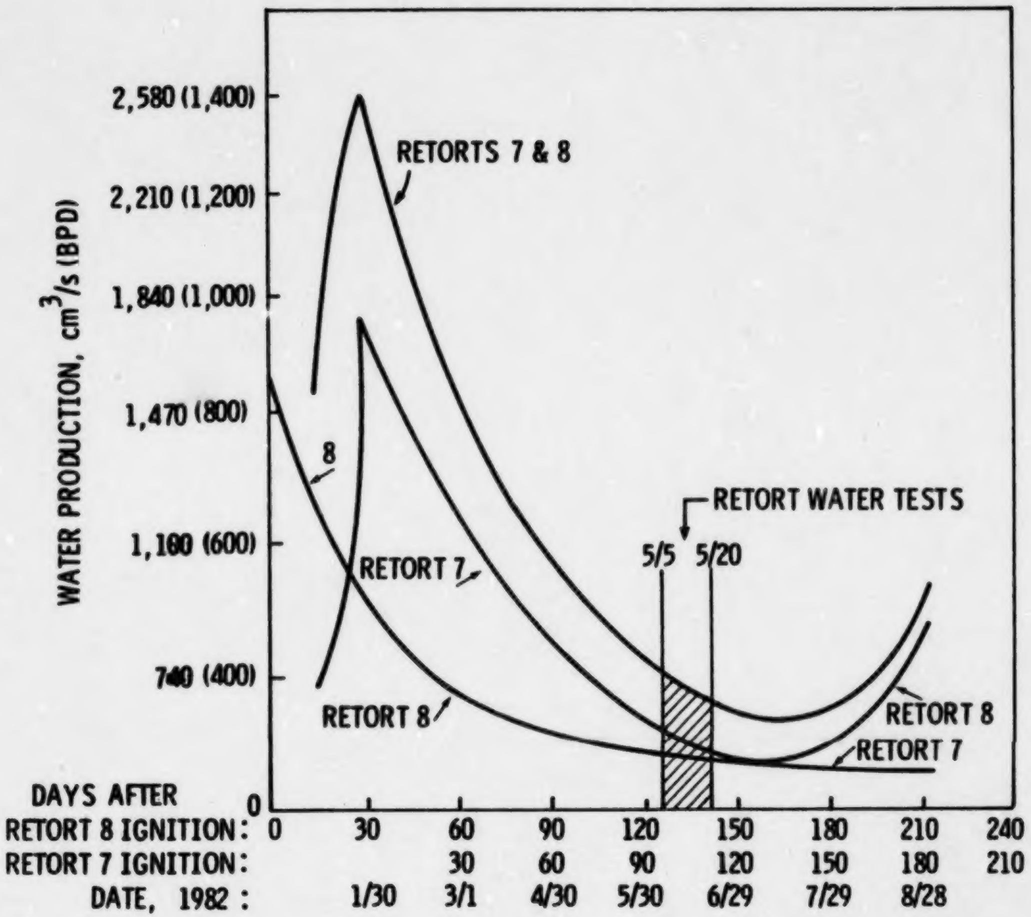


Figure 5. Retorts 7 and 8 retort water production rate (approximate).

3.4.2 Gas Condensate

Retorting of oil shale generates gases from shale pyrolysis, combustion of carbonaceous residues, and decomposition of inorganic carbonates such as dolomite and calcite. Typically, water vapor, ammonia, hydrogen sulfide, carbon dioxide, and organics are present. The off-gases exit the retort bottom and are brought to the surface and condensed to a liquid. This condensate is contaminated with light oils, dissolved organic compounds, ammonia, and minor concentrations of metallic elements. In addition, a high concentration of alkalinity (dissolved carbon dioxide) resulting in a pH of approximately 9.0 and a very high buffering capacity, is present. MIS processes may produce approximately 0.8 m^3 (0.8 barrel) of gas condensate water per cubic meter (barrel) of crude shale oil [4].

At the Logan Wash site, the off-gases from Retorts 7 and 8 were brought to the surface at the top of the mountain and, after passing through a series of contact coolers, were discharged to the atmosphere. The condensate formed upon cooling the off-gases flowed into holding tanks which facilitated oil/water separation and oil removal. A portion of the oil-free gas condensate stream was cooled in the fin coolers and subsequently used to contact the retort off-gases in the contact coolers to form new condensate. The unused portion of the condensate was expected to require some treatment before discharge or disposal. A general schematic diagram of gas condensate formation at Retorts 7 and 8 is provided in Figure 6. The gas condensate used in the treatability tests was supplied from the surface level at point B indicated in Figure 6. Retorts 7 and 8 gas condensate production rate over the test period ranged from 3,400 cm^3/s to 3,800 cm^3/s (1,840 barrels per day to 2,050 barrels per day) as illustrated in Figure 7.

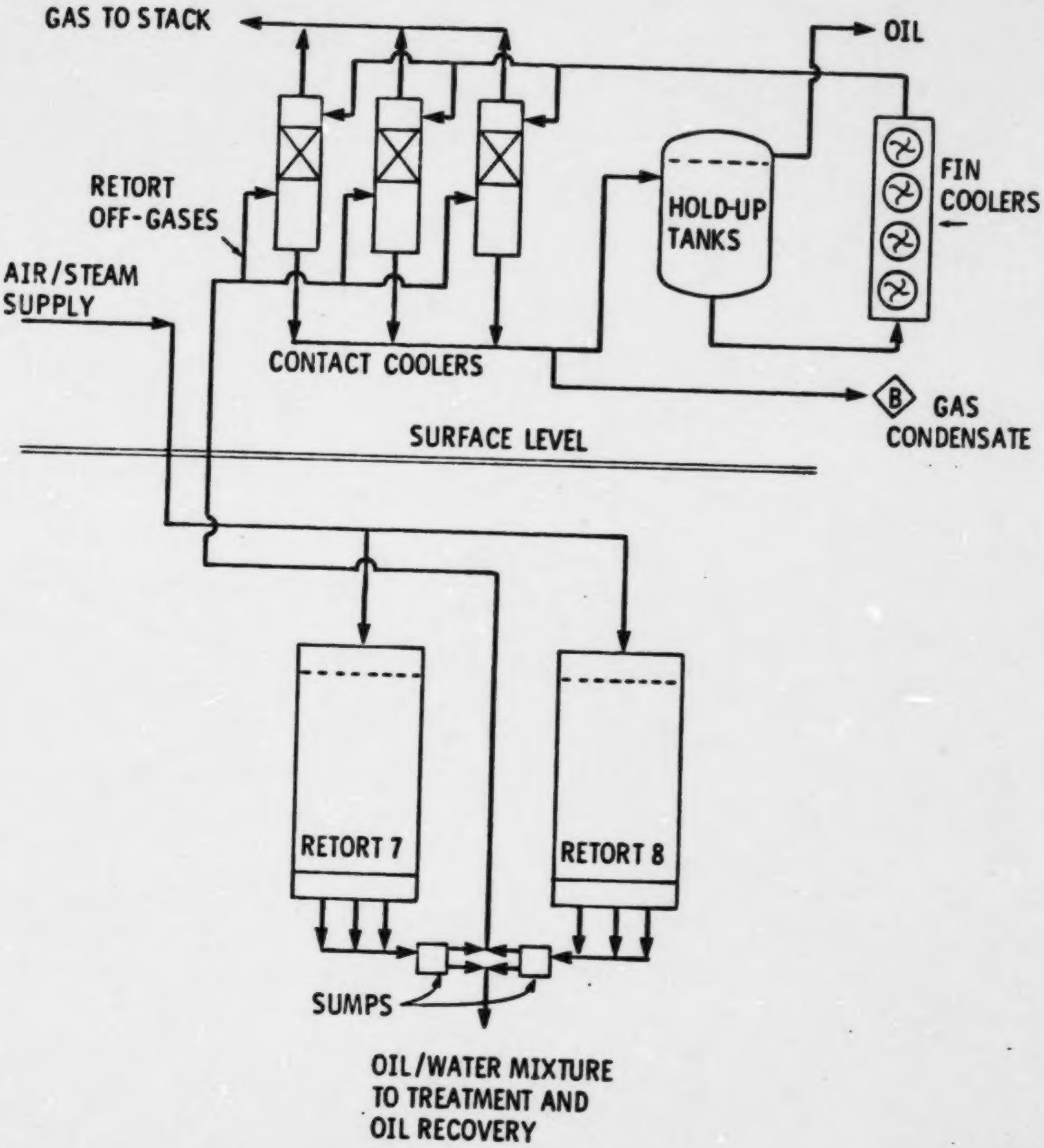

GAS TO STACK
OIL
RETORT OFF-GASES
AIR/STEAM SUPPLY
HOLD-UP TANKS
FIN COOLERS
CONTACT COOLERS
B
GAS CONDENSATE
SURFACE LEVEL
RETORT 7
RETORT 8
SUMPS
OIL/WATER MIXTURE TO TREATMENT AND OIL RECOVERY

Figure 6. Gas condensate supply point.

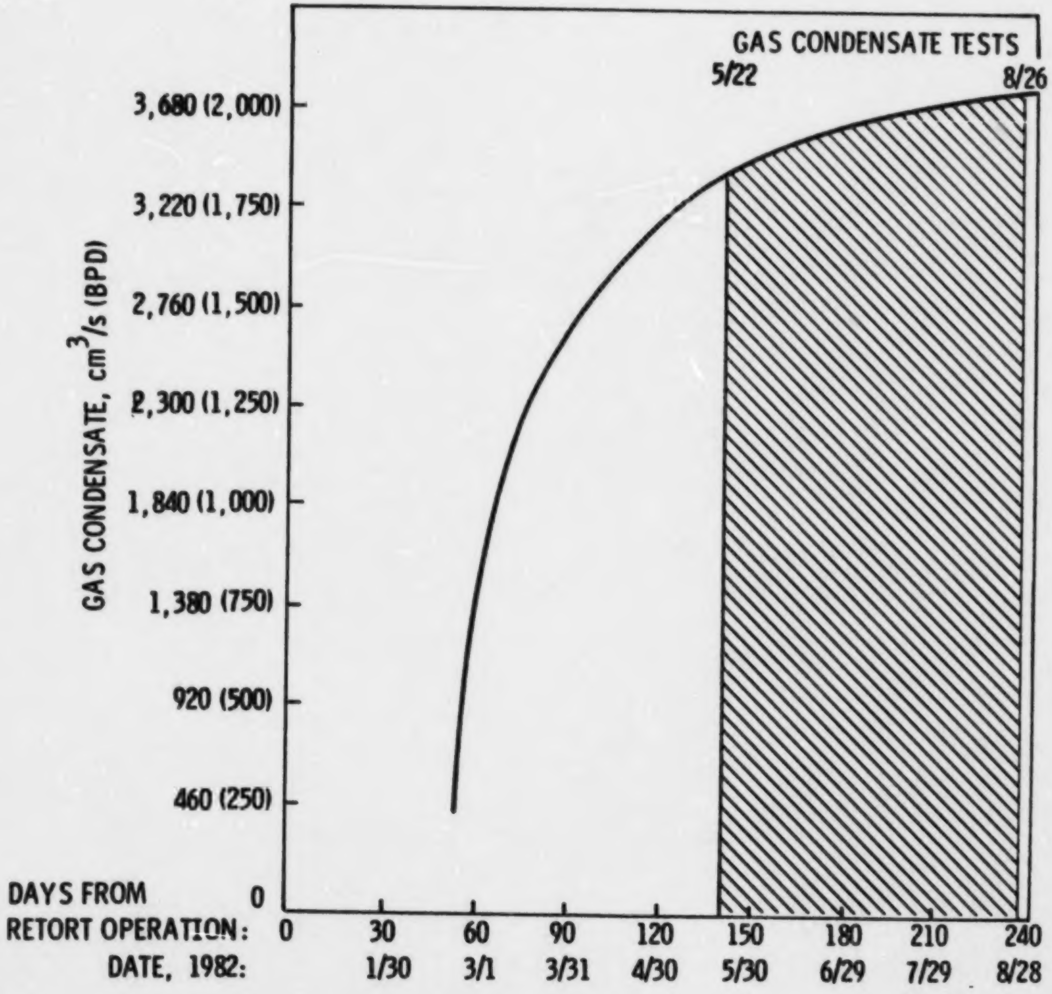


Figure 7. Retorts 7 and 8 gas condensate production rate (approximate).

3.5 WASTEWATER TREATMENT SCHEMES

After extensive review of proposed approaches to treatment of the retort water and gas condensate [1] and through a series of laboratory treatability and wastewater characterization studies, two treatment schemes to remove contaminants typically found in the retort water and gas condensate were identified and proposed for testing at Occidental's Logan Wash test site [2]. The retort water testing scheme was subsequently reduced in scope for financial reasons and because of site test time availability constraints. The finalized treatment schemes are described below.

3.5.1 Retort Water Treatment

The treatment scheme proposed for retort water is shown in Figure 8. It comprised filter coalescing, flocculation/clarification, and steam stripping. These steps were intended to remove residual oil, suspended solids, and dissolved gases from the retort water. The filter coalescer was to enhance gravity removal of free oils, even though the retort water available for testing at Logan Wash had undergone primary oil/water separation prior to its use. Effluent from the filter coalescer, expected to contain colloidal and possibly emulsified oils and fine suspended solids, passed through a flocculator/clarifier to remove these suspended materials and reduce the potential for fouling the steam stripping unit. Finally, steam stripping provided an effective means for removing ammonia and alkalinity from retort water.

3.5.2 Gas Condensate Treatment

The treatment scheme proposed for gas condensate treatability testing is illustrated in Figure 9.

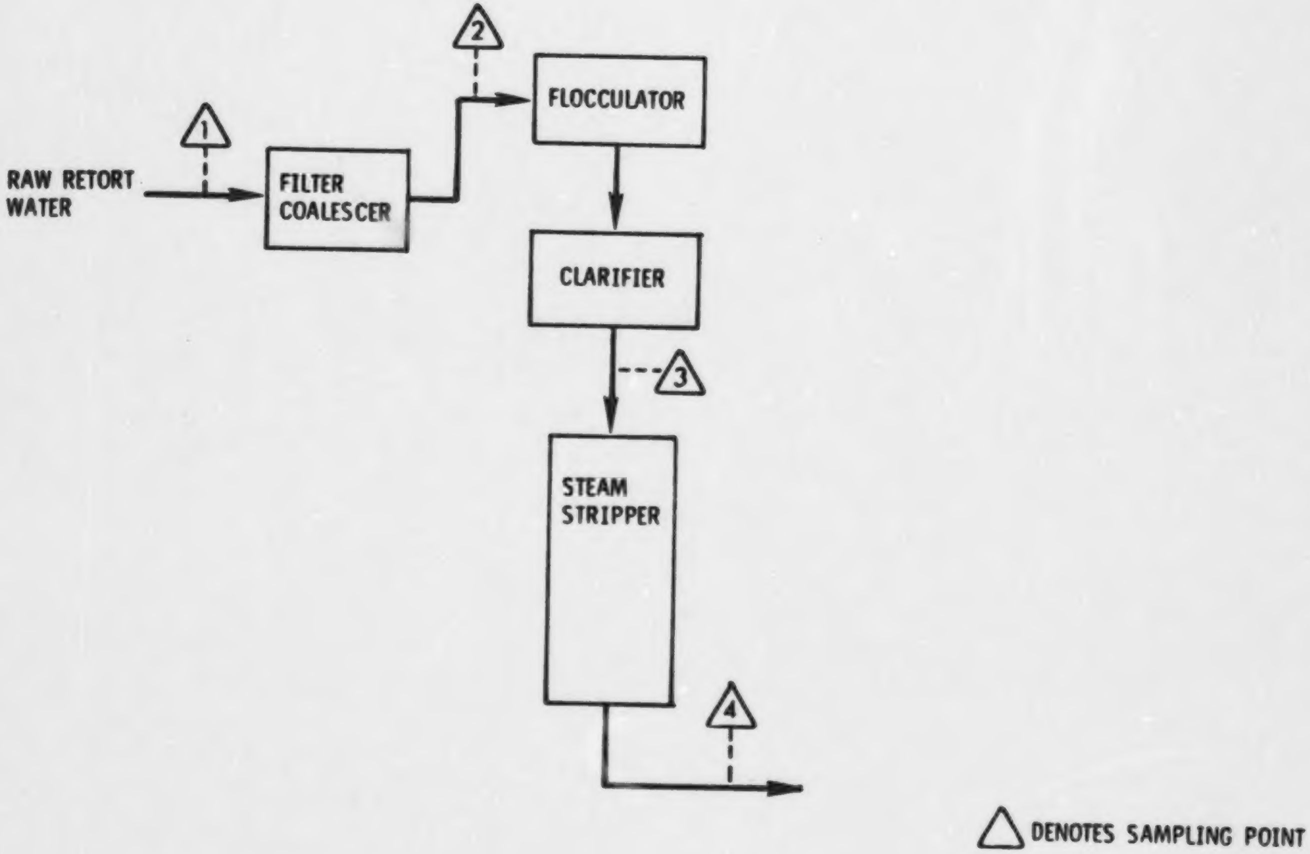

RAW RETORT WATER
1
FILTER COALESCER
2
FLOCCULATOR
CLARIFIER
3
STEAM STRIPPER
4
△ DENOTES SAMPLING POINT

Figure 8. Retort water treatment scheme.

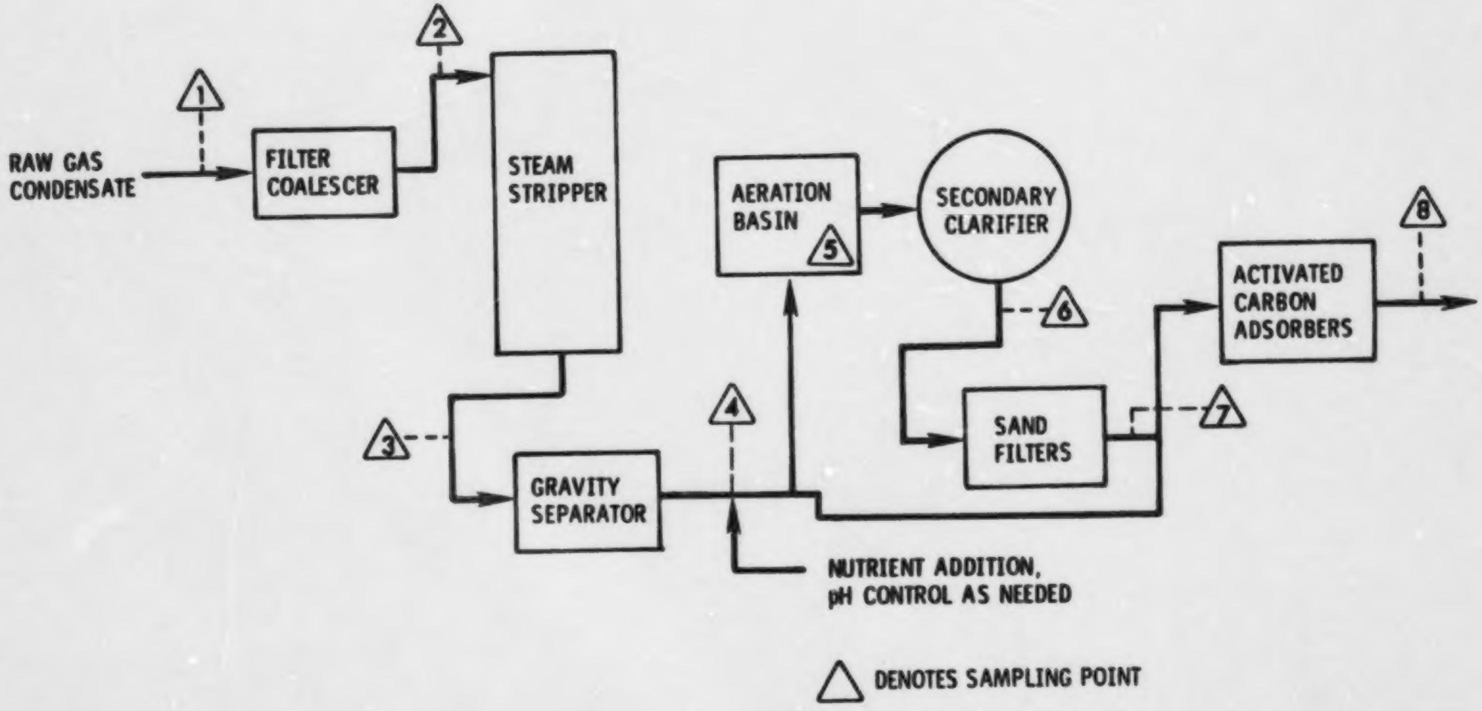

RAW GAS CONDENSATE
1
FILTER COALESCER
2
STEAM STRIPPER
3
GRAVITY SEPARATOR
4
NUTRIENT ADDITION, pH CONTROL AS NEEDED
AERATION BASIN
5
SECONDARY CLARIFIER
6
SAND FILTERS
7
ACTIVATED CARBON ADSORBERS
8
DENOTES SAMPLING POINT

Figure 9. Gas condensate treatment scheme.

Two oil/water separation steps were provided for oil/water separation. The filter coalescer was to remove free oil and minor concentrations of suspended solids from raw gas condensate. The gravity separator installed after, the steam stripper, was to assure that oil separated due to breaking any oil/water emulsion upon heating the wastewater in the steam stripper will be removed and not foul or otherwise interfere with operation of downstream units. Steam stripping was included to reduce the high levels of ammonia and alkalinity in the gas condensate. It also was expected to remove a considerable fraction of the volatile organic compounds as well, thereby altering the organic loadings on downstream treatment units. Following the gravity separator, an activated sludge system (aeration basin/clarifier) and/or activated carbon adsorption were proposed for further removal of organic materials from the steam-stripped and oil-free gas condensate. To prevent fouling of the activated carbon adsorbers, the effluent from the secondary clarifier, which was expected to contain residual suspended solids of largely bacterial origin, was passed through sand filters. Granular activated carbon adsorbers were used to remove residual dissolved organic compounds from the activated sludge effluent or the steam stripper effluent (following gravity separation) to complete the proposed gas condensate treatment scheme.

The gas condensate treatment scheme was tested during the fourteen weeks from May 22 through August 27, 1982, and information was developed on both conventional and powdered activated carbon (PAC) addition biological treatments.

3.6 FIELD TRIAL EQUIPMENT AND SETUP

Except for the steam stripper and filter coalescer, equipment for the field trials was procured by EPA and made available to this study. The steam stripper and filter coalescer were procured under this contract.

The equipment procured by EPA comprised eleven skid-mounted treatment units housed in two 13.7-m (45-ft) long, fully enclosed trailers and a field analytical laboratory built into a 7.6-m (25-ft) house trailer. The skid mounted units were furnished fully instrumented and piped, and they were arranged inside the trailers in accordance with the flow of the two treatment schemes described earlier. The eleven treatment units, including a flocculator, four clarifiers, a compartmented aeration basin, two sand filter columns, two granular activated carbon columns, a backwash module, a trickling filter (not used in field testing), and an anaerobic filter (not used in field testing; it was delivered after the field tests were completed) provided the bulk of treatment capability needed for testing the proposed treatment schemes in the field.

The equipment was freighted to the site, requiring an area of 18-m x 24-m (60-ft x 80-ft). The area levelled by Occidental on the slopes of the oil product level was at an elevation of 2,300 m (7,700 ft). The arrangement of the pilot plant equipment at this location is shown in Figures 10 through 13. Several auxiliary systems had to be installed to facilitate the field tests (refer to Figure 10). These included the electrical switchgear, five storage tanks, and freshwater supply and distribution system.

A 15-m^3 (4,000-gal) water tank was used to supply municipal water. The tank was filled twice a week with municipal water. The water from this tank was distributed to all locations, including the boiler, laboratory trailer, safety shower, and several all-purpose water hoses. Another 15-m^3 (4,000-gal) tank, filled with No. 2 fuel oil on an as-needed basis, was used to supply fuel to the steam boiler.

A 23-m^3 (6,000-gal) tank on the terrace (see Figures 11 and 12) built on the mountain slope 18 m (60 ft) above the pilot plant location provided for an uninterrupted supply of wastewater. The was filled twice a day with the wastewater being tested. The retort water was pumped into the tank from the measuring tank (Tank 6), which was on the same product level. The gas condensate was supplied by gravity through 370 m (1,200 ft) of high-pressure hose connecting the contact condenser at the mountain top with the wastewater supply tank (the black tank installed on a bench above product level as shown in Figures 11 and 12). Flow of either retort water or gas condensate wastewater from the wastewater supply tank to the pilot treatment units was by gravity.

Two additional tanks were installed to contain the treated effluent and the wastes generated by the field analytical laboratory.

A 1.1-m^3 (300-gal) effluent sump tank, installed one meter (3 ft) below the product level and fed by gravity, was used as a holding tank for all treated effluent. This is the white, half-buried tank in Figure 13. When actuated by a level sensor inside the tank, a sump pump at the tank bottom emptied the tank automatically, returning the contents to the Occidental mine sump. A 2-m^3 (500-gal) tank buried underground was used to receive all laboratory wastes except COD analysis wastes and was emptied periodically by a local contractor who hauled the wastes to a municipal sewage treatment plant for disposal. COD analysis waste was collected separately and treated (by precipitating the mercury and silver with sodium chloride and sulfide addition) before disposal in the laboratory waste tank.

The following subsections provide brief descriptions of equipment used during the Logan Wash study.

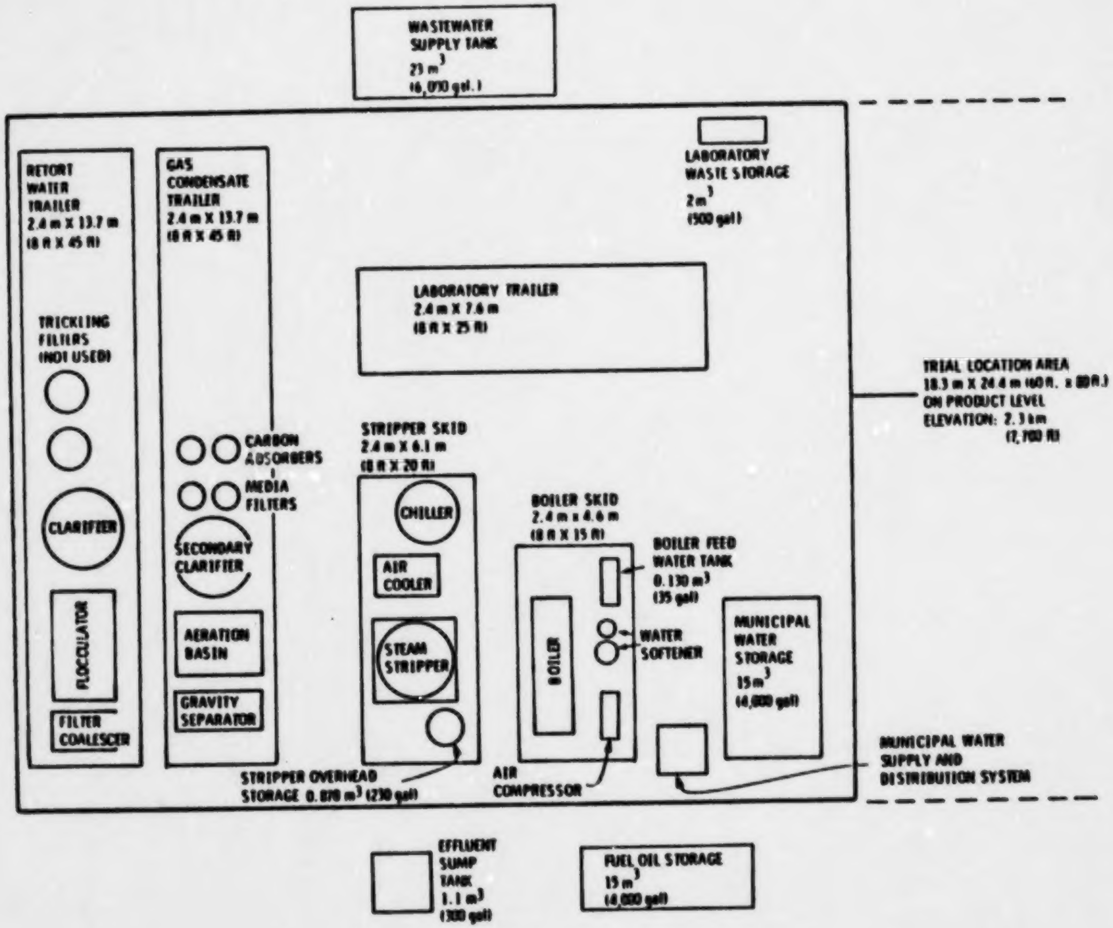

WASTEWATER SUPPLY TANK
23 m³
(6,070 gal.)
RETORT WATER TRAILER
2.4 m X 13.7 m
(8 ft X 45 ft)
TRICKLING FILTERS (NOT USED)
CLARIFIER
FLOCCULATOR
FILTER COALESCER
GAS CONDENSATE TRAILER
2.4 m X 13.7 m
(8 ft X 45 ft)
CARBON ADSORBERS
MEDIA FILTERS
SECONDARY CLARIFIER
AERATION BASIN
GRAVITY SEPARATOR
LABORATORY TRAILER
2.4 m X 7.6 m
(8 ft X 25 ft)
LABORATORY WASTE STORAGE
2m³
(500 gal)
STRIPPER SKID
2.4 m X 6.1 m
(8 ft X 20 ft)
CHILLER
AIR COOLER
STEAM STRIPPER
STRIPPER OVERHEAD STORAGE 0.870 m³ (230 gal)
BOILER SKID
2.4 m x 4.6 m
(8 ft X 15 ft)
BOILER
BOILER FEED WATER TANK
0.130 m³
(35 gal)
WATER SOFTENER
AIR COMPRESSOR
MUNICIPAL WATER STORAGE
15m³
(4,000 gal)
MUNICIPAL WATER SUPPLY AND DISTRIBUTION SYSTEM
TRIAL LOCATION AREA
18.3 m X 24.4 m (60 ft. x 80 ft.)
ON PRODUCT LEVEL
ELEVATION: 2.3 km
(7,700 ft)
EFFLUENT SUMP TANK
1.1 m³
(300 gal)
FUEL OIL STORAGE
15 m³
(4,000 gal)

Figure 10. General equipment layout at the trial location.

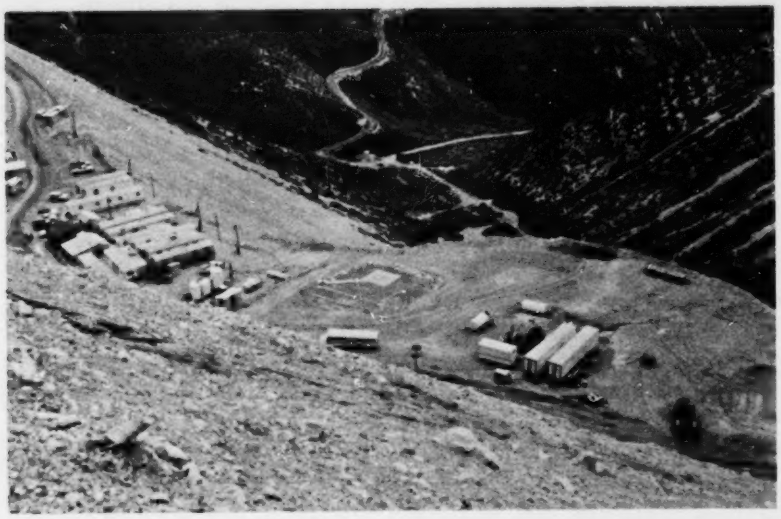


Figure 11. Access road, Occidential's trailer park, and pilot equipment position.

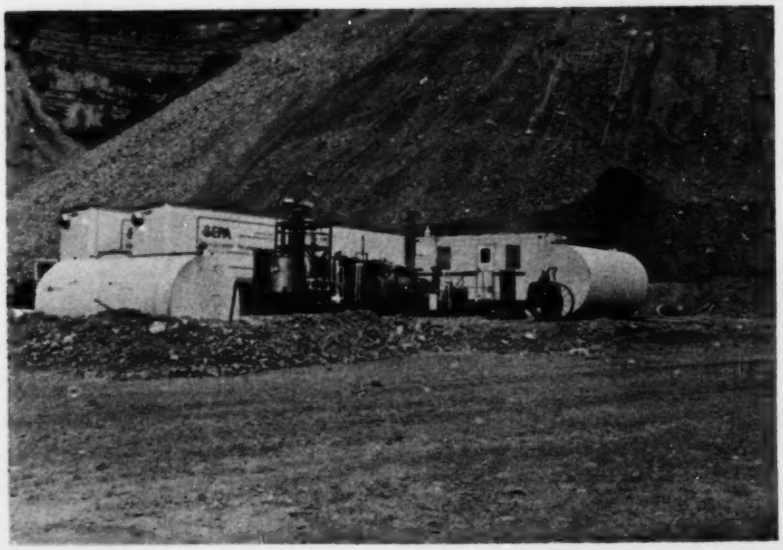


Figure 12. Field setup of wastewater treatment facilities at Logan Wash - general view.

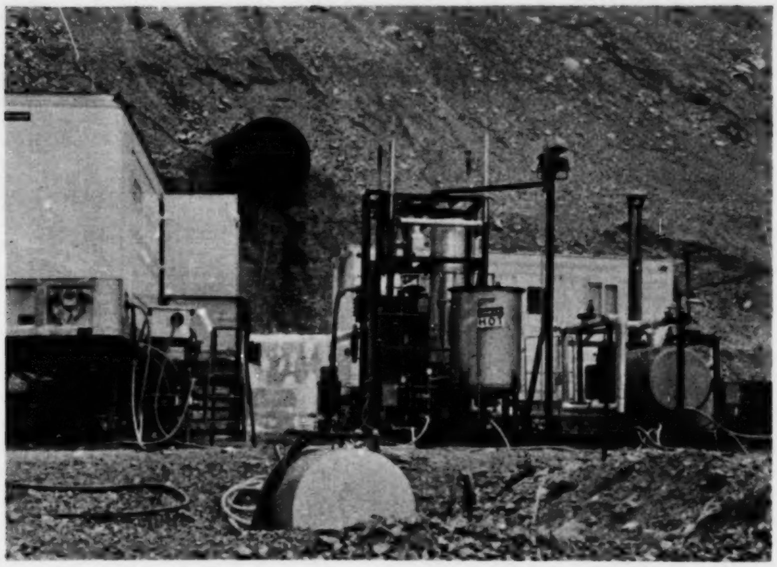


Figure 13. Field setup of wastewater treatment facilities at Logan Wash - closeup.

3.6.1 Filter Coalescer

The filter coalescer is illustrated in Figure 14. This unit, made of fiberglass with PVC inlet and outlet connecting flanges, was used to separate and remove residual oil from the raw wastewaters. It is rated to handle a water flow of up to 0.3 m^3/s (5 gal/min).

The coalescer employs a battery of perforated polypropylene tubes. The oleophilic (oil-attracting) properties of these vertically arranged tubes attract particles of oil from the water. As larger oil globules develop, they either wick up the tubes or, if sufficiently large, they break free and float to the surface. Oil from the surface drains by gravity over an adjustable weir to the slop tank section, and the cleaned water, after passing under the retention baffle, is discharged.

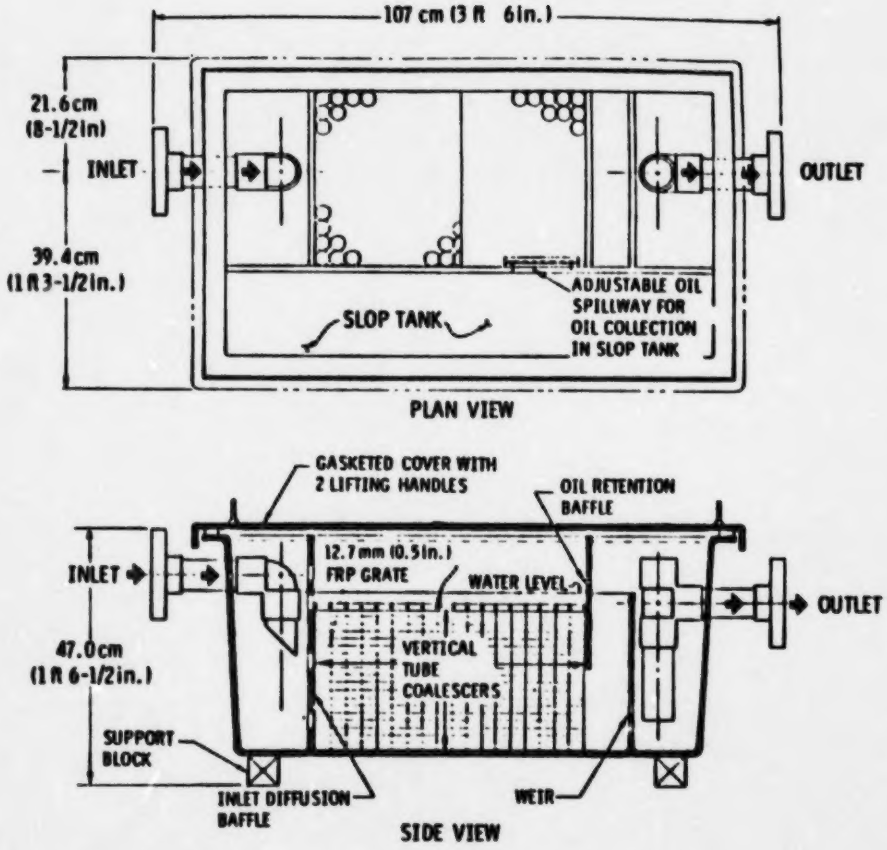

107 cm (3 ft 6in.)
21.6cm (8-1/2in)
INLET
OUTLET
39.4cm (1 ft 3-1/2in.)
ADJUSTABLE OIL SPILLWAY FOR OIL COLLECTION IN SLOP TANK
SLOP TANK
PLAN VIEW
GASKETED COVER WITH 2 LIFTING HANDLES
OIL RETENTION BAFFLE
INLET
12.7mm (0.5in.) FRP GRATE
WATER LEVEL
OUTLET
47.0cm (1 ft 6-1/2in.)
VERTICAL TUBE COALESCERS
SUPPORT BLOCK
INLET DIFFUSION BAFFLE
WEIR
SIDE VIEW

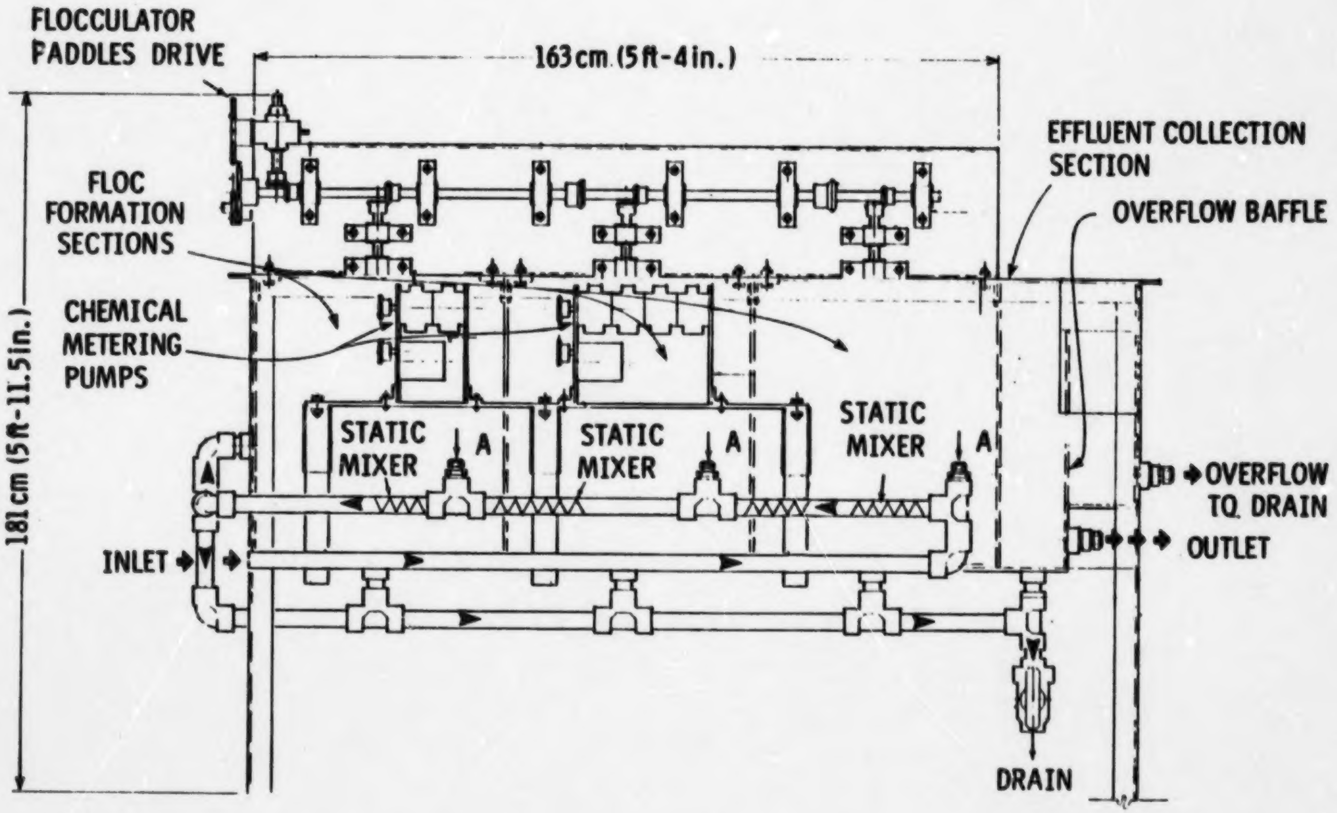
Figure 14. Filter coalescer.

3.6.2 Flocculator

The flocculator, shown in Figure 15, is a 163-cm long x 76-cm wide x 181-cm high (5 ft 4-in. long x 2 ft 6-in. wide x 5 ft 11.5-in. high) rectangular module. The flocculator holding vessel is constructed of 304 stainless steel with PVC connecting pipes and fittings. It is designed for up to 20 minutes of hydraulic detention time at flows of up to 0.158 m^3/s (2.5 gal/min). The flocculator has four sections separated by walls. A 1.9-cm (0.75-in.) hole in each wall permits the water to flow from one section to the next. The first three floc formation sections are equipped with a low-energy flocculator paddle. The three paddles, driven by a common variable-speed drive, rotate at speeds of 0 to 200 rev/s. The three sections are interconnected by PVC piping through a single opening in the bottom of each section to permit flushing and removal of settled floc. The desired detention time can be obtained by varying the influent flow rate. Flocculating (chemical conditioning) agents are added through one or more of the three ports (identified by the letter A in Figure 15) by means of variable-speed chemical metering pumps. The ports are interconnected with sections of static mixers, which assure initial mixing of flocculating agents with the influent. The treated water from the third section, after passing through an effluent collection section, is discharged through an outlet port. The effluent collection section has a baffle and a port to handle overflow from this section.

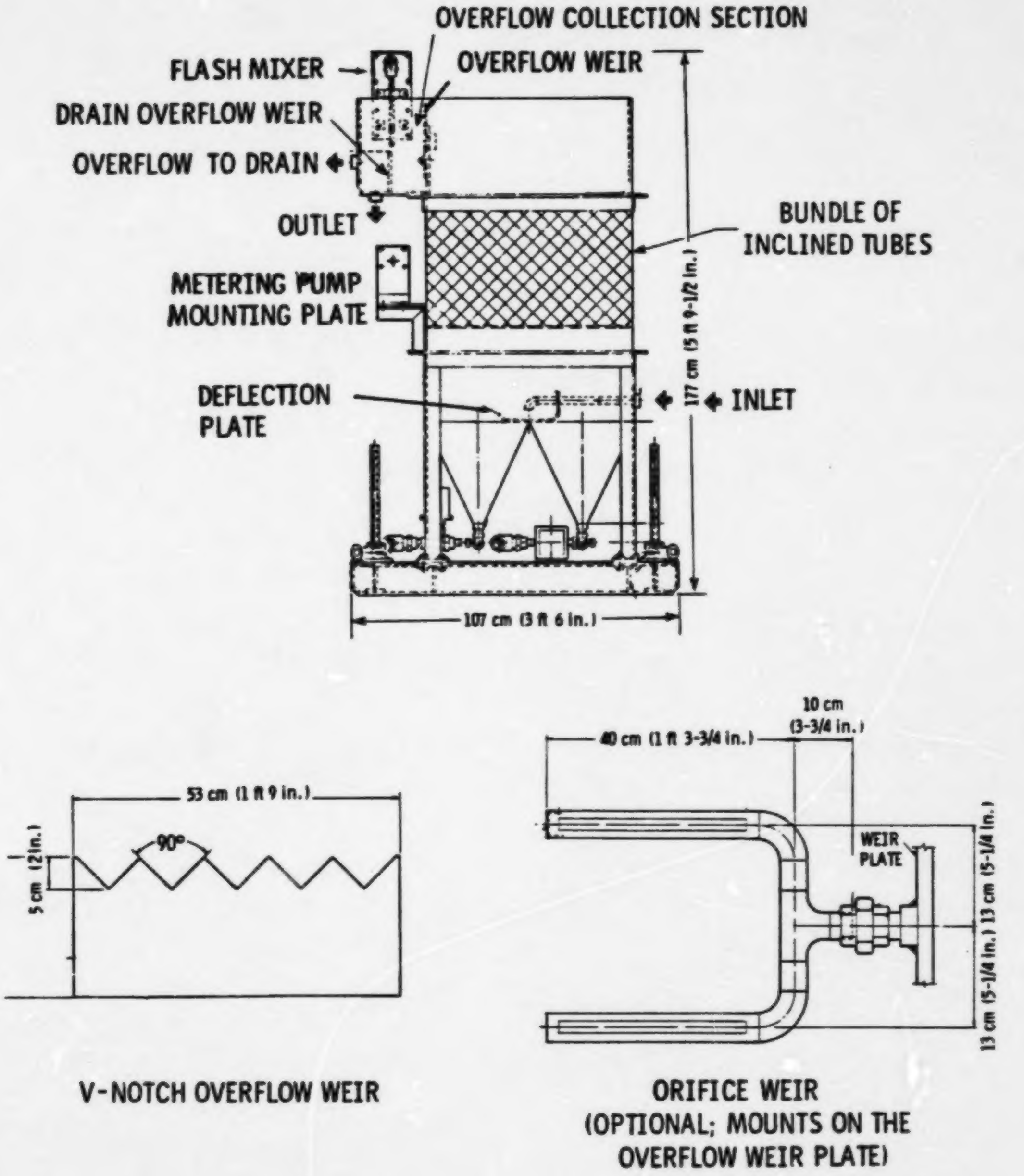
3.6.3 Primary Clarifiers

The primary clarifiers, shown in Figure 16, are rectangular tanks constructed of 304 stainless steel. They are 107 cm long x 107 cm wide x 177 cm high (3 ft 6 in. long x 3 ft 6 in. wide x 5 ft 10 in. high) and have conical bottoms. The section above the cones contains a 45-cm (1 ft 6-in.) tall bundle of inclined plastic settling tubes and and an inlet flow deflection plate which


FLOCCULATOR PADDLES DRIVE
163cm (5ft-4in.)
EFFLUENT COLLECTION SECTION
FLOC FORMATION SECTIONS
OVERFLOW BAFFLE
CHEMICAL METERING PUMPS
STATIC MIXER
A
STATIC MIXER
A
STATIC MIXER
A
181cm (5ft-11.5in.)
A
OVERFLOW TO DRAIN
INLET
OUTLET
DRAIN

"A" SIGNIFIES FLOCCULANT ADDITION PORTS

Figure 15. Flocculator.


OVERFLOW COLLECTION SECTION
FLASH MIXER
OVERFLOW WEIR
DRAIN OVERFLOW WEIR
OVERFLOW TO DRAIN
OUTLET
BUNDLE OF INCLINED TUBES
METERING PUMP MOUNTING PLATE
177 cm (5 ft 9-1/2 in.)
DEFLECTION PLATE
INLET
107 cm (3 ft 6 in.)
53 cm (1 ft 9 in.)
90°
5 cm (2 in.)
10 cm (3-3/4 in.)
40 cm (1 ft 3-3/4 in.)
WEIR PLATE
13 cm (5-1/4 in.)
13 cm (5-1/4 in.)

V-NOTCH OVERFLOW WEIR

ORIFICE WEIR
(OPTIONAL; MOUNTS ON THE
OVERFLOW WEIR PLATE)

Figure 16. Primary clarifier.

minimizes turbulence in the clarifier. Each clarifier handles overflow rates up to 3.8 x 10^{-4} $m^3/m^2 \cdot s$ (800 gpd/ft^2) at corresponding throughput rates up to 132 cm^3/s (2.1 gal/min).

The influent enters the clarifier at the center of the tank 6.4 cm (2.5 in.) above the cones through a nozzle that is pointed down toward the deflection plate. As the water slowly rises in the clarifier, solids settle into the cones by gravity. The treated water overflows into the effluent collection section through an orifice or V-notch weir (the orifice weir provides for oil/water separation prior to discharge). The effluent collection section is equipped with chemical metering pumps, a flash mixer or a turbidity meter. The settled solids from the cones are removed by opening the four (one for each cone) motor-operated ball valves, which are automatically controlled by a programmer. The programmer can operate the valves in any desired sequence, at any desired frequency, and for any desired duration.

3.6.4 Secondary Clarifier

The secondary clarifier is quite similar to the primary clarifiers, so only the features different from those of the primary clarifier are described below.

The secondary clarifier module is a 137-cm (4 ft 6-in.) long, 107-cm (3 ft 6-in.) wide, and 161-cm (5 ft 4-in.) high rectangular tank, and it is designed for overflow rates up to 2.8 x 10^{-4} $m^3/m^2 \cdot s$ (600 gpd/ft^2) at influent flow rates up to 132 cm^2/s (2.1 gal/min). It has dissolved oxygen and turbidity meters for effluent monitoring. The settled sludge from the four cones flows to a common sludge line from which it is either returned to the aeration basin or disposed of as waste.

3.6.5 Aeration Basin

The aeration basin, shown in Figure 17, is a 335-cm (11-ft) long, 145-cm (4 ft 10-in.) wide, 213-cm (7-ft) high unit comprising a 3.8-m^3 (1,000-gal) compartmentalized rectangular tank made of 304 stainless steel. The unit, used for biological treatment of wastewater, is capable of accomodating the following operating conditions:

Hydraulic detention time:	3.6-28.8 ks (1-8 h)
Sludge recycle ratio:	0-1.5
Food-to-microorganism ratio:	0.2-1.5
Organic loading:	0.6-59.8 x 10^{-6} kg $BOD_5/s/m^3$ (37.4-3,740 lb BOD_5/day/1,000 ft^3)

The hydraulic detention time can be varied by the use of specific sections and/or by varying influent flow rate.

The aeration basin has four sections with respective volumes of 0.950 m^3 (250 gal), 0.475 m^3 (125 gal), 0.475 m^3 (125 gal), and 1.90 m^3 (500 gal). The four sections are connected by a 1.9-cm (0.75-in.) diameter hole through each of the section walls and can be operated individually or in parellel. Each section has its own variable-speed agitator and an air diffuser to provide both mixing and the air required to keep the biological mass suspended and aerobic. The air, supplied to the four air diffusers by a common blower, is measured for each section by an air rotameter. Each section is monitored for dissolved oxygen by its own dissolved oxygen meter.

The influent enters the aeration basin through an influent manifold that distributes it into desired sections at controlled rates through use of flow-splitting orifices and plugs. The overflow from each section is collected by a common overflow line from which it is gravity fed to the secondary clarifier.

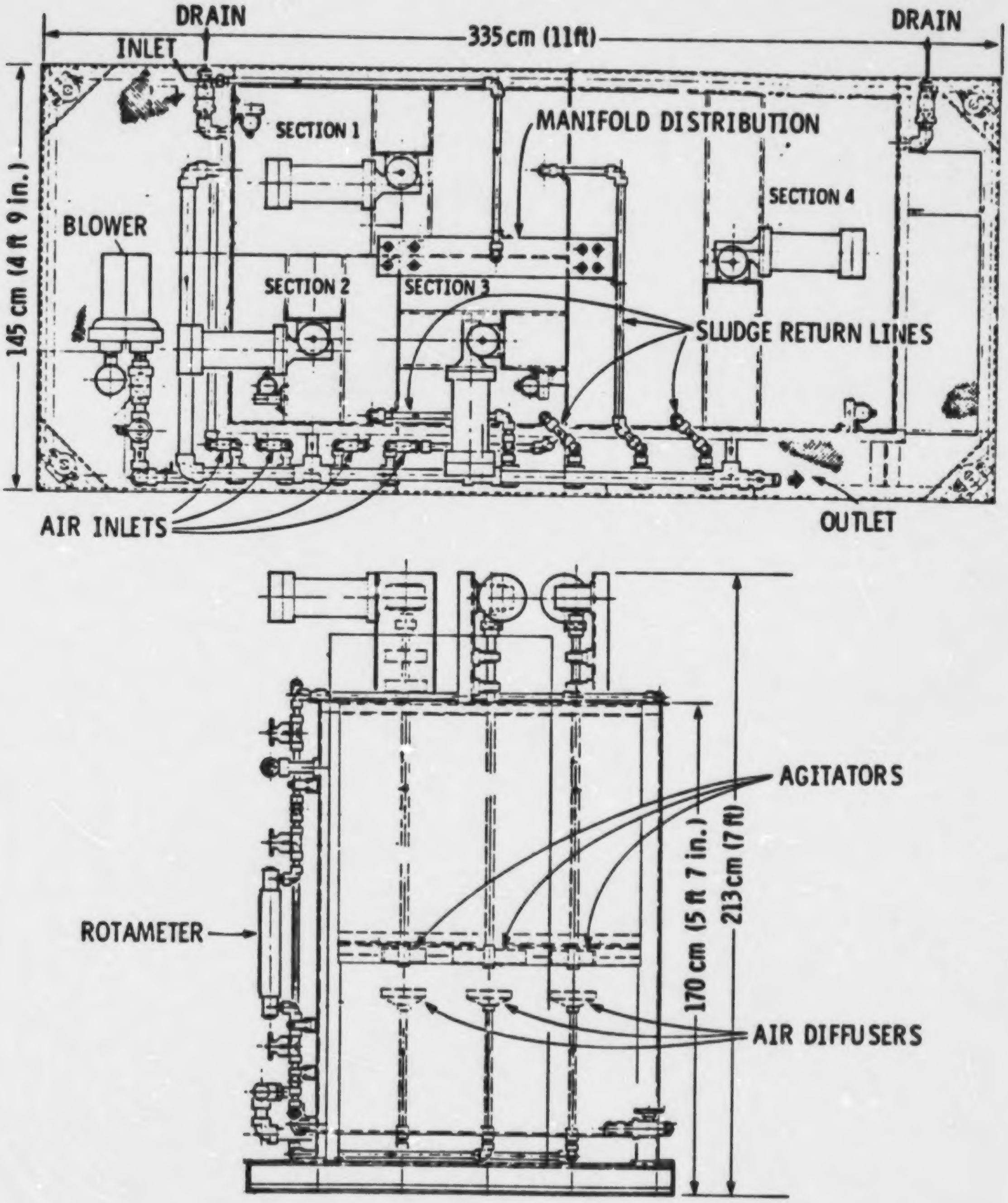

DRAIN
335 cm (11ft)
DRAIN
INLET
SECTION 1
MANIFOLD DISTRIBUTION
SECTION 4
145 cm (4 ft 9 in.)
BLOWER
SECTION 2
SECTION 3
SLUDGE RETURN LINES
AIR INLETS
OUTLET
AGITATORS
ROTAMETER
170 cm (5 ft 7 in.)
213 cm (7 ft)
AIR DIFFUSERS

Figure 17. Aeration basin.

A separate line for each section is provided for the return of activated sludge from the secondary clarifier. Each line has a rotameter and a diaphragm valve to monitor and control the rate of return of activated sludge.

3.6.6 Sand Filters

The sand filtration module, shown in Figure 18, is a 117-cm (3 ft 9 in.) long, 112-cm (3 ft 8 in.) wide, 267-cm (8 ft 9 in.) high unit comprised of two 7.6-cm (3-in.) diameter, 236-cm (7 ft 9-in.) long clear PVC columns. The bottom flange of the columns has a filter media-retaining screen and silk cloth with quick connects to facilitate air scouring and backwashing. The columns, used for filtration of suspended solids from the wastewater, have a design capacity of $1.4\text{-}14 \times 10^{-3}$ $m^3/m^2 \cdot s$ (2-20 gpm/ft^2), and can be operated in parallel or series. During testing, the columns were filled with 12 x 40 mesh sand, approximately 1.7 m (5.5 ft) in depth and operated in parallel.

Influent wastewater is pumped into the top of the column by a variable-speed pump and flows down the column through the filter medium. The filtered effluent enters a standpipe and is discharged. The standpipe maintains a constant liquid level in the filter columns. A rotameter monitors the flow through the columns, and turbidity meters are provided to monitor the turbidity of each column effluent. The pressure drop across each column is measured by pressure differential measurement cells.

3.6.7 Carbon Adsorption Columns

The carbon adsorption column module is identical to the filtration module described in Section 3.6.6 except that the columns are 15.2 cm (6 in.) diameter instead of 7.6 cm (3 in.). The columns were packed with virgin activated carbon having the following characteristics:

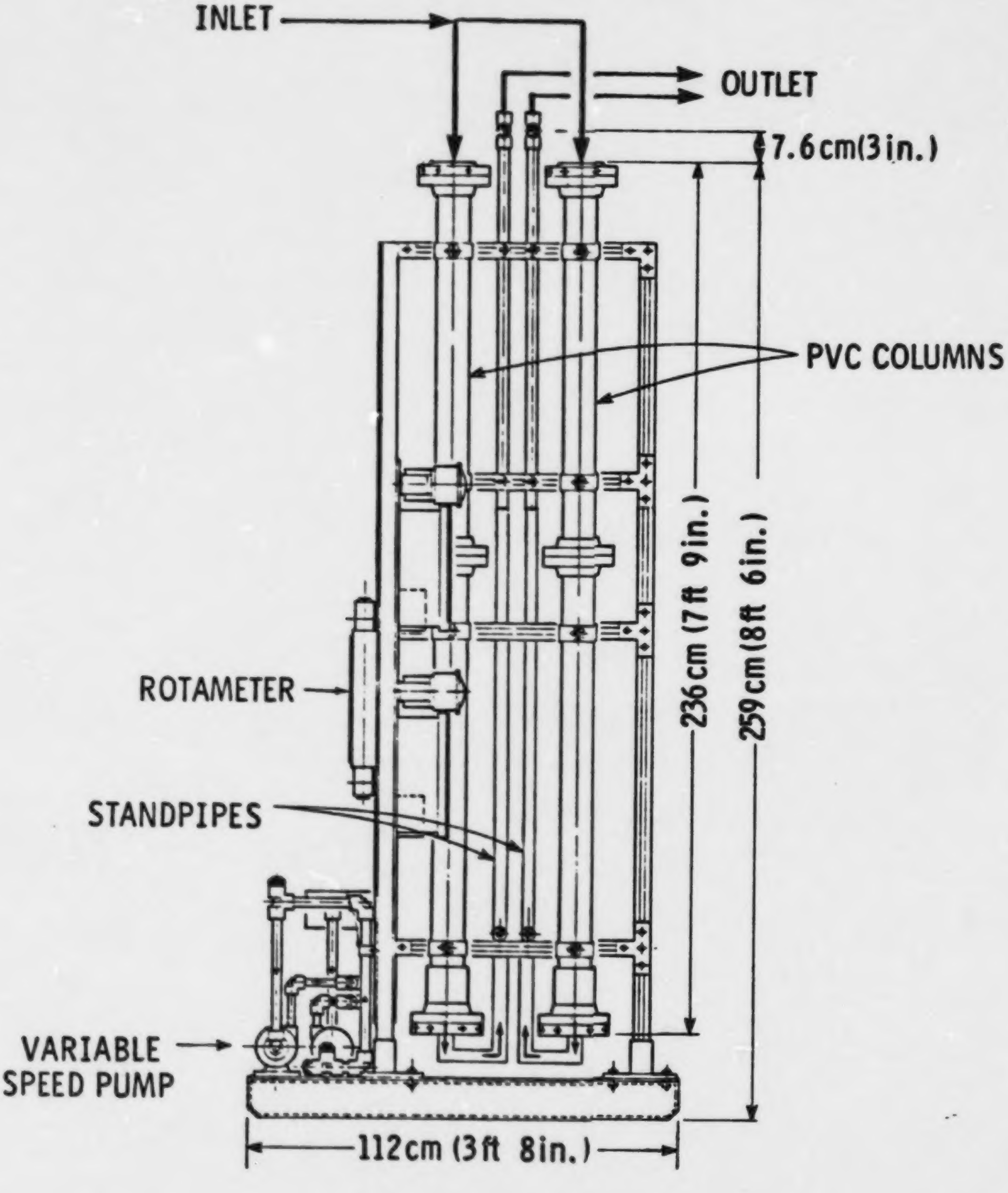

INLET
OUTLET
7.6 cm (3 in.)
PVC COLUMNS
ROTAMETER
STANDPIPES
236 cm (7 ft 9 in.)
259 cm (8 ft 6 in.)
VARIABLE SPEED PUMP
112 cm (3 ft 8 in.)

Figure 18. Sand filters.

Surface area: 1,525 m^2/g
Apparent density: 340 kg/m^3
Larger than No. 12 mesh: 3% (maximum)
Smaller than No. 40 mesh: 3% (maximum)
Iodine No.: 1,265 mg/g (minimum)
Abrasion No.: 65 (minimum)

3.6.8 Backwash Module

The backwash module is 86 cm (2 ft 9 in.) long, 81 cm (2 ft 7 in.) wide, and 102 cm (3 ft 4 in.) high. As shown in Figure 19, it is comprised of a water pump and an air compressor. The air and water flowrates are controlled using separate rotameter and diaphragm valve systems, respectively. The unit is used for air scouring and backwashing of filtration and carbon adsorption columns.

3.6.9 Boiler Module

The boiler module, shown in Figure 20, is 457 cm (15 ft) long, 244 cm (8 ft) wide, and 140 cm (4 ft 7 in.) high. It is comprised of a boiler, a boiler feedwater tank, a water softener, and an air compressor. The module is used to deliver steam to the steam-stripping column. It is designed to deliver up to 110 g/s (860 lb/h) of steam at 103 kPa (15 psig) gauge pressure.

The boiler feedwater is pumped through the water softener, which has an automatic resin regeneration capability using common salt pellets, into the boiler feedwater tank. The water is pumped from the feedwater tank into the boiler by a pump that is actuated by the water level in the boiler. The boiler, which is fired with No. 2 fuel oil, shuts off automatically when a preset steam pressure is achieved. The air compressor provides air to the pneumatically controlled instruments on the steam-stripper skid.

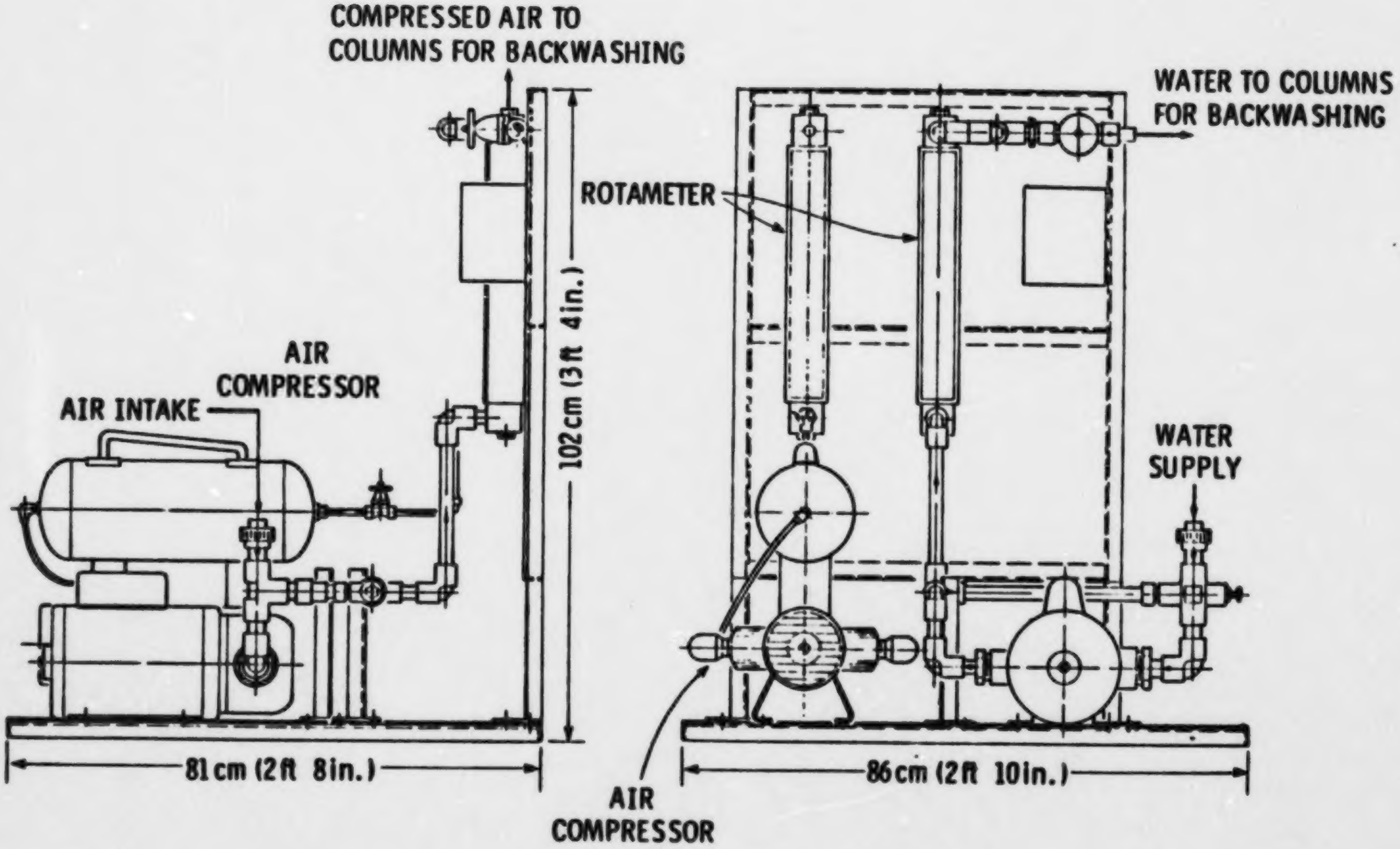

COMPRESSED AIR TO
COLUMNS FOR BACKWASHING
AIR INTAKE
AIR
COMPRESSOR
102cm (3ft 4in.)
81cm (2ft 8in.)
ROTAMETER
WATER TO COLUMNS
FOR BACKWASHING
WATER
SUPPLY
AIR
COMPRESSOR
86cm (2ft 10in.)

Figure 19. Backwash module.

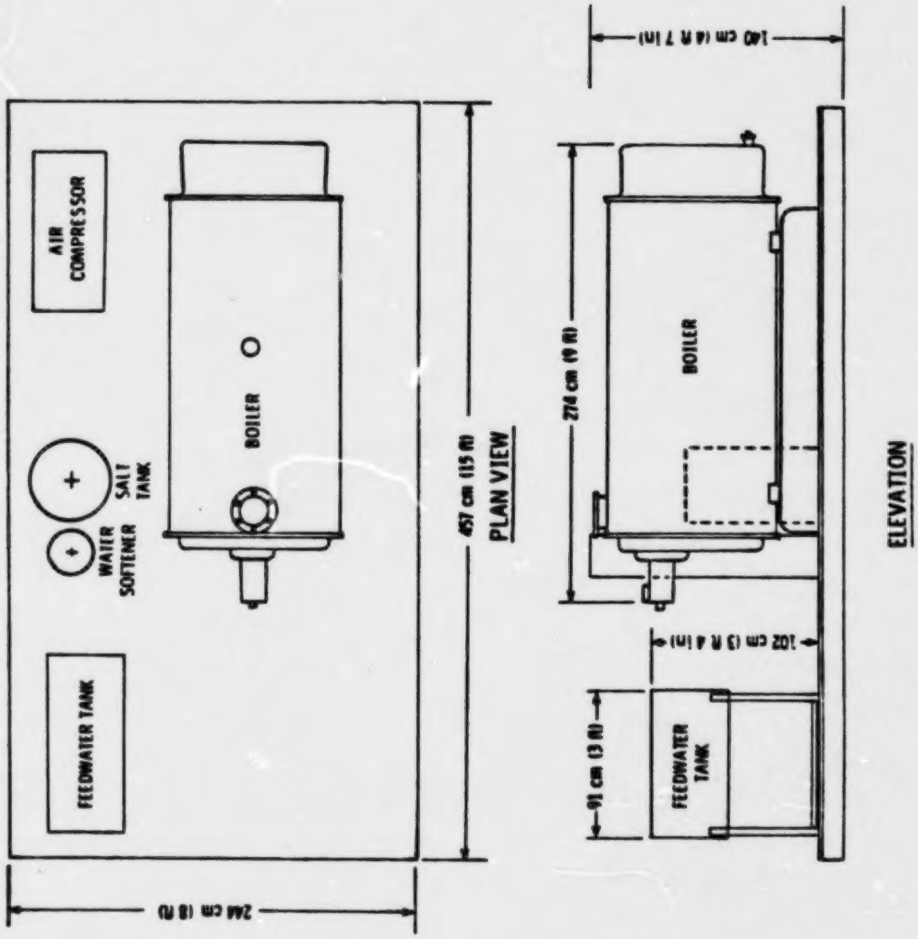
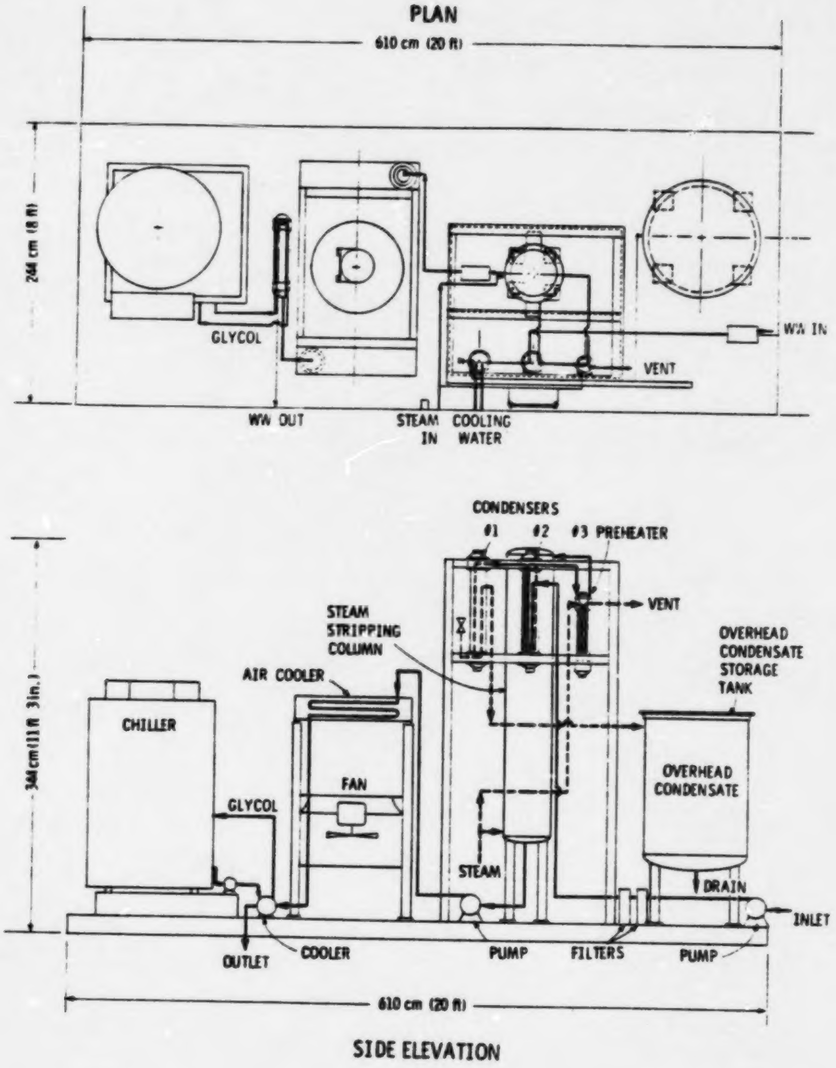

AIR COMPRESSOR
SALT TANK
WATER SOFTENER
BOILER
FEEDWATER TANK
457 cm (15 ft)
PLAN VIEW
244 cm (8 ft)
140 cm (4 ft 7 in)
274 cm (9 ft)
BOILER
102 cm (3 ft 4 in)
91 cm (3 ft)
FEEDWATER TANK
ELEVATION

Figure 20. Boiler skid.

3.6.10 Steam Stripper

The steam stripper module, shown in Figure 21, is 610 cm (20 ft) long, 244 cm (8 ft) wide, and 344 cm (11 ft 4 in.) high. It is comprised of a packed column, an air cooler, a chiller, and an overhead vapor condensate storage tank. Instrumentation and automatic controls are provided to monitor and control the operation of equipment on the stripper skid with minimal operator attention. The unit, used for removal of dissolved gases from wastewaters, is designed for liquid throughputs of up to 378 cm^3/s (6 gal/min) and steam rates up to 91 g/s (720 lb/h).

The stripping column, made of 316 stainless steel, is 40 cm (1 ft 3 3/4 in.) in diameter and 244 cm (8 ft) high. It is packed with 170 cm (5 ft 6 in.) of Goodloe® packing, a high-efficiency stainless steel wire mesh with 95% void space. The air cooler is a forced-air-cooled, finned-tube heat exchanger designed to cool up to 378 cm^3/s (6 gal/min) of water from temperatures near boiling to 49°C (120°F) at air temperatures below 38°C (100°F). Five fans, each having 5.6 m^3/s (11,800 ft^3/min) capacity, are used to force the air around the finned tubes and remove heat from the water passing through the tubes. The air cooler is 138 cm (4 ft 6 in.) long, 104 cm (4 ft 5 in.) wide, and 200 cm (6 ft 7 in.) high. The chiller is a packaged, fully automated unit designed to deliver 35 kW (10 tons) of refrigeration energy. Glycol, refrigerated inside the chiller and circulated at a constant rate through an external shell-and-tube heat exchanger, is used as a cooling and heat transfer medium. The chiller is 137 cm (4 ft 6 in.) long, 130 cm (4 ft 3in.) wide, and 183 cm (6 ft) high. The 91-cm (3-ft) diameter, 142-cm (4 ft 8 in.) high overhead vapor condensate storage tank is made of stainless steel and has a holding capacity of 0.870 m^3 (230 gal).


PLAN

SIDE ELEVATION

610 cm (20 ft)
244 cm (8 ft)
GLYCOL
WW OUT
STEAM IN
COOLING WATER
VENT
WW IN
CONDENSERS
#1
#2
#3 PREHEATER
VENT
STEAM STRIPPING COLUMN
AIR COOLER
OVERHEAD CONDENSATE STORAGE TANK
CHILLER
FAN
GLYCOL
OVERHEAD CONDENSATE
STEAM
DRAIN
INLET
344 cm (11 ft 3in.)
OUTLET
COOLER
PUMP
FILTERS
PUMP
610 cm (20 ft)

Figure 21. Steam stripper skid.

Feedwater, after passing through a 50-micron filament cartridge filter and two heat exchangers (No. 2 and No. 3), is fed to the top of the column where, by means of a distribution plate, it is dispersed over the packing and trickles down through the column by gravity. The filter is used to remove any suspended solids and prevent clogging of the column packing. Two filter cartridges connected in parallel are employed and used interchangeably to permit uninterrupted column operation. The two heat exchangers, connected in series, are used to preheat the feedwater to near boiling temperature. Heat exchanger No. 2 uses column overhead vapors, and No. 3 uses steam as the heating media.

Steam is introduced at the bottom of the column and exits at the top. As it passes through, the steam heats and strips the feedwater of the volatile components.

The column overhead vapors are either vented to the atmosphere or condensed by two heat exchangers (No. 1 and No. 2). Heat exchanger No. 1 uses cooling water and No. 2 uses column feedwater as cooling media. A storage tank is provided for overhead vapor condensate storage.

3.6.11 Pilot Equipment Trailers

Two semitrailers, Figure 22, each 13.7 m (45 ft) long, 2.4 m (8 ft) wide, and 2.6 m (8 ft 6 in.) high were used to house the pilot treatability equipment modules. Each trailer has a side and back door, a feedwater pump and flow monitoring instruments, Unistrut rails for fastening equipment, a sink, an emergency eyewash and shower, an exhaust fan, a space heater, electrical outlets, and an effluent discharge line.

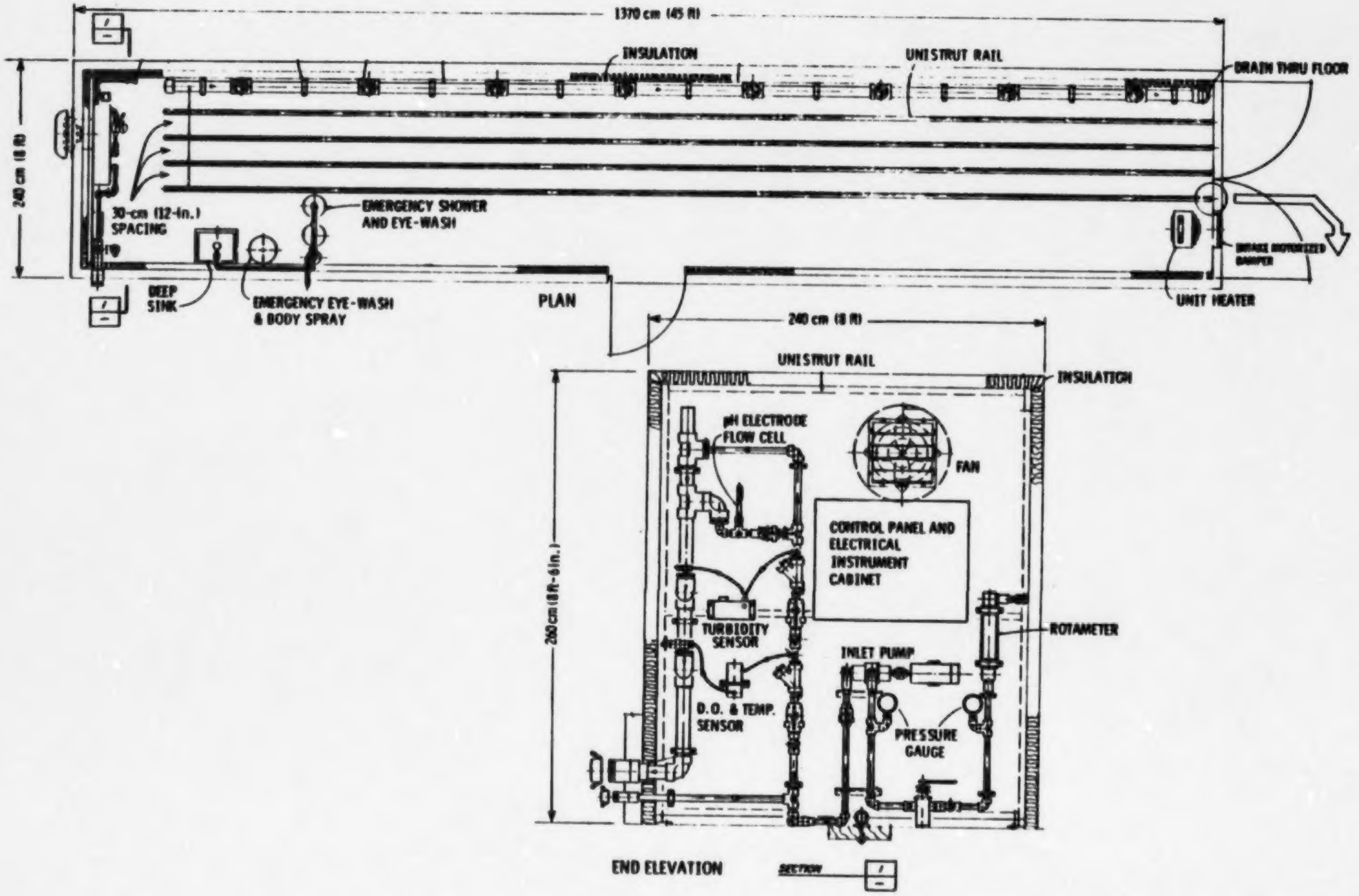

1370 cm (45 ft)
240 cm (8 ft)
INSULATION
UNISTRUT RAIL
DRAIN THRU FLOOR
30-cm (12-in.) SPACING
EMERGENCY SHOWER AND EYE-WASH
DEEP SINK
EMERGENCY EYE-WASH & BODY SPRAY
PLAN
INTAKE MOTORIZED DAMPER
UNIT HEATER
240 cm (8 ft)
UNISTRUT RAIL
INSULATION
260 cm (8 ft-6 in.)
pH ELECTRODE FLOW CELL
FAN
CONTROL PANEL AND ELECTRICAL INSTRUMENT CABINET
ROTAMETER
TURBIDITY SENSOR
INLET PUMP
D.O. & TEMP. SENSOR
PRESSURE GAUGE
END ELEVATION
SECTION

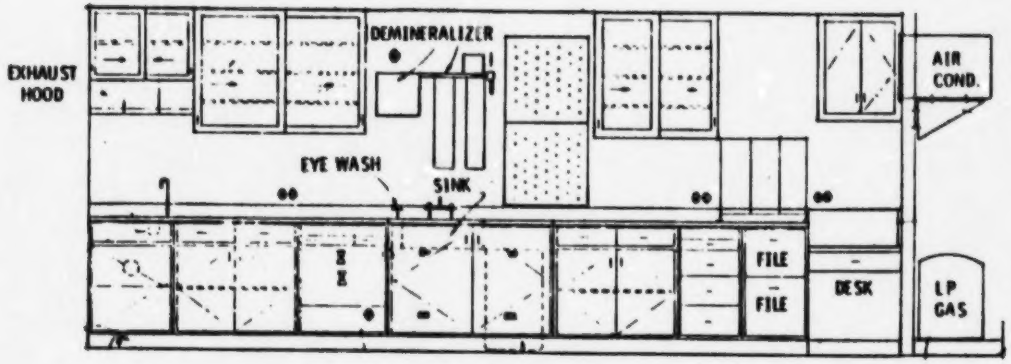
Figure 22. Pilot equipment trailer.

Primarily the side door was used for personnel access and the back door for equipment installation and removal. Quick-disconnect male couplers are provided outside the trailer for feedwater and monitoring loop effluent hookups. Two pressure gauges, a basket strainer, and a rotameter are located in the influent line to measure pressure, to remove large-size coarse solids, and to measure flow rate, respectively. During operation, a variable-speed influent pump transfers the wastewater to be treated from its supply point to the first treatment unit. A small fraction of the influent stream passes through a loop for measurement of dissolved oxygen, temperature, turbidity, and pH, and then proceeds to the drain.

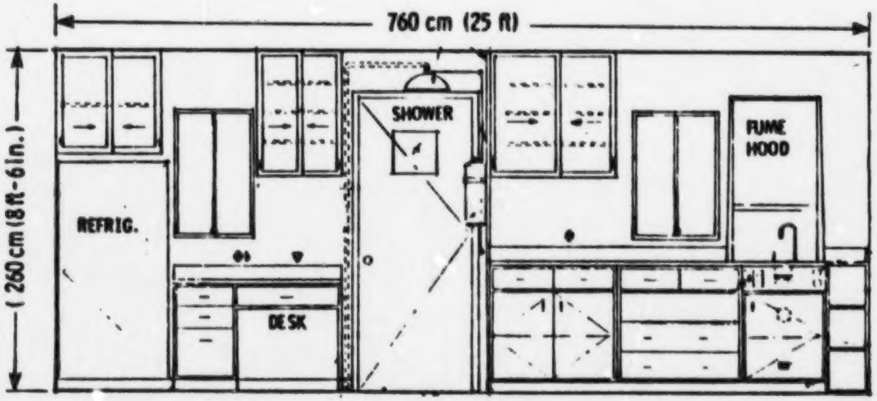
Four Unistrut rails were provided to securely fasten the skid-mounted treatment modules in the trailer. An acid-resistant sink, an emergency eyewash, and an emergency shower were provided with municipal and drain hookups underneath the trailer. An exhaust fan circulates air through the trailer to prevent buildup of vapors from the treatment operations. A series of electrical outlets (110/220/440 V) were provided along the trailer wall to supply power to pilot equipment. A 10.2-cm (4-in.) diameter PVC pipe with multiple inlets is located on the floor for discharge of effluent from the treatment units in the trailer.

3.6.12 Mobile Laboratory Trailer

A mobile laboratory trailer, 7.6 m (25 ft) long, 2.4 m (8 ft) wide, and 2.4 m (8 ft) high, shown in Figure 23, was used to conduct field laboratory analyses. The trailer is equipped with basic laboratory glassware, reagents, other support supplies, an analytical balance, a triple-beam balance, a microscope, a gas chromatograph, a muffle furnace, an oven, a vacuum pump, a spectrophotometer, a COD analyzer, a specific-ion meter with pH, dissolved oxygen and ammonia probes, a calculator with printer, 4 m^2 (45 ft^2) of bench space, a fume hood, cabinets and drawers, a kitchen hood,


EXHAUST HOOD
DEMINERALIZER
EYE WASH
SINK
AIR COND.
FILE
FILE
DESK
LP GAS

ELEVATION - PORT SIDE


760 cm (25 ft)
(260 cm (8 ft-6 in.)
REFRIG.
DESK
SHOWER
FUME HOOD

ELEVATION - STARBOARD SIDE

Figure 23. Mobile laboratory trailer.

a refrigerator, a dishwasher, a sink, a desk, a space heater, an air conditioner, a water demineralizer, LPG racks, and brackets for compressed gas cylinder storage.

SECTION 4

PROGRAM IMPLEMENTATION AND RESULTS

After considerable preparation and planning, the tests began on May 5, 1982. Initial testing was performed with retort water for sixteen consecutive days. Two days were needed to perform equipment and minor plumbing changes and to set up for gas condensate testing, which began on May 22. The gas condensate testing lasted 14 weeks and was terminated on August 27. After two days of equipment decommissioning and site restoration activities, the equipment was removed from the site on September 2 and returned to MRC's Dayton Laboratory for further servicing and maintenance.

A chronological listing of the more important events are given in Table 1. It provides an overview of the Logan Wash test program and permits relating the most important events to the program results and vice versa.

4.1 PROGRAM SAMPLING AND ANALYSIS SCHEDULE

To identify components in the streams before and after treatment and to evaluate the performance of each treatment step as well as of the entire treatment scheme, a significant number of analyses were performed on samples collected at predetermined locations in the treatment schemes (refer to Figures 8 and 9). Unless dictated otherwise by upsets or selective equipment performance evaluations (e.g., determinations of steam stripping efficiency as a function of steam-to-water ratio, or evaluation of flocculator removal with

TABLE 1. PROGRAM MAJOR EVENTS

Dates	
1981	
12/27	Retort 8 ignition
1982	
2/1	Retort 7 ignition
3/1	Retorts 7 and 8 reach steady state
4/3	Test equipment arrives at the trial location
4/26	Field laboratory arrives at the trial location
5/4	All systems installed and in working condition
5/5	Start retort water tests
5/5 - 5/16	Test filter coalescer, flocculator/clarifier with fixed lime dosage, and steam stripper with varying G/L ratio and constant liquid throughput of 190 cm^3/s (3 gal/min)
5/16 - 5/18	Test filter coalescer, flocculator/clarifier with variation in lime dosage, and steam stripper with fixed G/L ratio of 160 kg of steam per cubic meter of liquid throughput (1.5 lb of steam per gallon) and constant liquid feed of 190 cm^3/s (3 gal/min)
5/19 - 5/20	Test steam stripper at 380 cm^3/s (6 gal/min) liquid throughput (unsuccessful)
5/20	End retort water tests
5/20 - 5/21	Equipment changeover in preparation for gas condensate tests
5/22	Start gas condensate tests
5/22 - 5/23	Test steam stripper with varying G/L ratio at a constant liquid throughput of 190 cm^3/s (3 gal/min)

(continued)

TABLE 1 (continued)

Dates	
1982	
5/25	Test filter coalescer, steam stripper, aeration basin (all four sections full; hydraulic detention time of 24 hours), and secondary clarifier
5/25	Seed aeration basin (bioreactor)
7/31	Increase PAC dosage to 2,000 mg/L in Section 1 PAC-activated sludge treatment
7/31	Inadvertent addition of PAC (1,000 mg/L) to conventional activated sludge system, Section 4 in aeration basin
8/10	End PAC-activated sludge system in Section 1 of the aeration basin
8/10	Conventional activated sludge system in Section 4 of the aeration basin converted to PAC-activated sludge system at 400 mg/L PAC dosage
8/23	Increase PAC dosage to 475 mg/L in Section 4 PAC-activated sludge system
8/24	Increase PAC dosage to 950 mg/L in Section 4 PAC-activated sludge system
8/25	Increase PAC dosage to 1,425 mg/L in Section 4 PAC-activated sludge system
8/26	Increase PAC dosage to 1,900 mg/L in Section 4 PAC-activated sludge system
8/27	End gas condensate tests
9/2	Transport test equipment to MRC's Dayton Laboratory
11/9	Retort 8 shutdown
11/19	Retort 7 shutdown

varying flocculant additions), the types and frequency of sampling and analyses performed during the retort water and gas condensate trials are indicated respectively in Tables 2 and 3.

TABLE 2. ANALYTICAL SCHEDULE - RETORT WATER[a,b]

Parameter	Raw wastewater	Filter coalescer effluent	Clarifier effluent	Steam stripper effluent
Total COD	3	3	3	-
Soluble COD	5	-	-	5
Total BOD_5	5	2	5	-
Soluble BOD_5	5	-	5	5
Dissolved organic carbon	5	-	5	5
Oil and grease	3	3	-	-
NH_3-N	5	-	-	5
Total Kjeldahl nitrogen	5	-	-	5
NO_3-N	2	-	-	-
Alkalinity	5	-	-	5
Sulfide	5	-	-	5
Phosphorus	1	-	-	-
Cyanide	2	-	-	2
Phenols	2	-	-	2
Fluoride	2	-	-	-
Metals	(1)	-	-	(1)
TSS	5	5	5	-
VSS	5	5	5	-
TDS	2	-	-	-
Organic compounds (by GC/MS)	(1)	-	-	(1)
pH	[1]	-	[1]	[1]
Temperature	[1]	-	-	[1]
Chlorides	2	-	-	-
DOC fractions	(1)	-	-	(1)

[a] Single numerical values indicate number of analyses per week. Parenthesized values indicate number of analyses during the entire study period. Bracketed values indicate number of analyses per day.

[b] Unless reported otherwise, all analyses performed on 24-h composite samples except for oil and grease, phenols, cyanide, pH, and temperature.

TABLE 3. ANALYTICAL SCHEDULE - GAS CONDENSATE[a,b]

Parameter	Raw wastewater	Filter coalescer effluent	Steam stripper effluent	Gravity separator effluent	Mixed liquor	Secondary clarifier effluent	Effluent for sand filters	Activated carbon effluent	Steam stripper overhead vapor condensate
Total COD	-	-	-	-	-	1[d]	-	-	-
Soluble COD	3	-	2	-	-	3	-	3	-
Total BOD_5	-	-	-	-	-	1[d]	-	-	-
Soluble BOD_5	1	-	1	-	-	3	-	2	-
Dissolved organic carbon	3	-	3	-	-	3	-	3	-
Oil and grease	2[c]	2[c]	-	1[c]	-	-	-	-	-
NH_3-N	[1]	-	[1]	-	-	2	-	-	-
Total Kjeldahl nitrogen	1	-	-	-	-	1	-	-	-
NO_3-N	1[c]	-	-	-	-	1	-	-	-
Alkalinity	2	-	2	-	-	-	-	-	-
Sulfide	1	-	1[c]	-	-	1[c]	-	-	-
Phosphorus	1[c]	-	-	-	-	-	-	-	-
Cyanide	1[c]	-	1[c]	-	-	1[c]	-	-	-
Phenols	1	-	1	-	-	1	-	1	-
Fluoride	1[c]	-	-	-	-	-	-	-	-
Metals	(1)	-	(1)	-	-	(1)	-	(1)	-
TSS	1[c]	2[c]	-	2[c]	3	[1]	2	-	-
VSS	1[c]	2[c]	-	2[c]	3	2	-	-	-
Total filtrable residue	1[c]	-	-	-	-	-	-	-	-
pH	[1]	-	[1]	-	[1]	-	-	-	-
Temperature	[1]	-	[1]	-	[1]	-	-	-	-
Dissolved oxygen	-	-	-	-	[1]	[1]	-	-	-
Oxygen uptake rate	-	-	-	-	2	-	-	-	-
Organic compounds (by GC/MS)	(1)	-	(1)	-	-	(1)	-	(1)	(1)
DOC Fractions	(1)	-	(1)	-	-	-	-	-	(1)

---

[a] Single numerical values indicate number of analyses per week. Parenthesized values indicate number of analyses during the entire study period. Bracketed values indicate number of analyses per day.

[b] Unless reported otherwise, all analyses performed on 24-h composite samples except for oil and grease, phenols, cyanide, pH, temperature, and activated carbon effluent.

[c] Due to observed low analyte concentrations these analyses were either deleted or conducted with irregular frequency to spot check the concentration.

[d] Due to no significant differences observed between total and soluble COD, these analyese were conducted with irregular frequency to spot-check the total COD and BOD_5 concentrations.

All analyses were performed in accordance with the Standard Methods for the Examination of Water and Wastewater, 15th Edition, 1980, except for nitrate nitrogen (ASTM D922), mercury, arsenic, and selenium (EPA Interim Method 200.7), organic compounds (EPA Methods 624 and 625), and DOC fractions (DOC fractionation procedure).

The following sections present the results from the Logan Wash treatability study of retort and gas condensate wastewaters.

4.2 RETORT WATER TEST RESULTS

Retort water testing was performed May 5, 1982 through May 18, 1982. In general, the treatment units were operated continuously 24 hours a day. For each treatment unit, the parameters listed in Table 4 were monitored on a periodic basis by the operating personnel and entered into the equipment operation log once every two hours. Samples of the influent and effluent were collected in accordance with the schedule presented in Table 2. Presentation and discussion of the results follow.

4.2.1 Raw Wastewater Characterization

Raw wastewater was analyzed for conventional pollutants, metals, and organics (by GC/MS and DOC fractionation). The results of these analyses, from samples collected over 16 days of retort water tests, are summarized in Tables 5 through 8. As expected, the results show that the raw retort water contained high concentrations of TDS, ammonia, TKN, organics, sulfide, alkalinity, phenols, chlorides, fluorides, boron, potassium, and sodium. Sixty-eight percent of the organics were hydrophobic; the remainder were hydrophilic.

TABLE 4. MONITORED EQUIPMENT OPERATING PARAMETERS DURING RETORT WATER TESTING

Filter coalescer

- Influent pH
- Influent temperature
- Influent flow
- Oil volume collected

Flocculator

- Mixing energy (RPM)
- Chemical (flocculant) added and its dosage

Primary clarifier

- Overflow pH

Steam stripper

- Column feed flow and temperature
- Steam flow and pressure
- Column bottoms flow, temperature and pH[a]
- Overhead flow and temperature
- Column temperature - top and bottom
- Column pressure - top and bottom
- Column level

Boiler

- Steam pressure
- Boiler water level
- Boiler feedwater tank level

As shown in Table 5, the TKN value is less than the NH_3-N value. This is not possible since TKN equals the sum of organic and ammonia nitrogen. This discrepency occurs throughout the retort water, gas condensate, and treatment unit performance data. Data will be presented and the reader should use his discretion. Unfortunately, causes for the discrepency can at best be estimated and may include the following:

TABLE 5. RAW RETORT WATER CHARACTERIZATION - CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS

Parameter	Number of analyses performed	Concentration, mg/L[a]	
		Range	Average
Total COD	4	3,400-6,000	4,700
Soluble COD	4	3,100-5,400	4,100
Total BOD_5	4	2,200-4,000	3,200
Soluble BOD_5	4	1,900-2,200	2,000
DOC	5	1,400-2,300	1,700
Oil and grease	(5)[b]	(50-170)	(110)
NH_3-N	6(5)	1,600-3,900	2,200
		(1,700-3,700)	(2,200)
TKN (N)	6(2)	1,700-3,000	2,100
		(2,100-2,200)	(2,100)
NO_3-N	5	3.0-4.8	4.3
Alkalinity as $CaCO_3$ to pH 4.5	6(4)	12,000-17,000	14,000
		(13,000-16,000)	(14,000)
Sulfide	3	50-130	90
Phosphorus (P)	4	0.8-2.1	1.5
Cyanide	(4)	(<0.02-0.08)	(0.05)
Phenols	(5)	(47-70)	(56)
Fluorides	7	36-63	45
Chlorides	6	500-1,000	800
TSS	8	27-93	59
VSS	6	23-78	54
TDS	6(1)	10,000-15,500	14,000
		(15,000)	(15,000)
pH	(10)	(8.6-9.4)	(8.8)
Temperature	(10)	(21-46)	(35)

[a] Except for pH and temperature; pH is reported in standard pH units, and temperature in °C.

[b] Data reported in parentheses pertain to grab samples; the other data pertain to 24-hr composite samples.

- TKN QA/QC is continuously poor; analyses was performed by an outside lab while NH_3-N analyses was performed internally.

- Interference by amines on the NH_3-N titrimetric method may cause false positive NH_3-N results.

- Available methods for TKN and/or NH_3-N analyses on wastewaters as complex as these oil shale waters may not be reliable.

TABLE 6. RAW RETORT WATER CHARACTERIZATION - METALS[a]

Parameter	Concentration, mg/L
Ag	<0.18
Al	0.22
As	4.9
B	37
Ba	0.14
Be	<0.01
Ca	4.3
Cd	0.01
Co	<0.06
Cr	0.05
Cu	0.05
Fe	0.65
K	170
Mg	2.3
Mn	0.01
Mo	1.2
Na	2,900
Ni	0.15
Pb	<0.42
Sb	<0.27
Se	0.04
Sn	5.8
Sr	0.29
Ti	<0.08
V	0.07
Zn	0.09

[a] One 24-hr composite sample taken on May 18, 1982.

- No organic Nitrogen is present and the TKN and NH_3-N values are within the effeciency of the sampling and analyses methods and (in some cases) are equal.

4.2.2 Oil/Water Separation

A filter coalescer, the first step in the treatment scheme, was used for oil/water separation. Its performance was evaluated at 220 cm^3/s (3.5 gal/min) throughput flow.

TABLE 7. RAW RETORT WATER CHARACTERIZATION - PURGEABLE AND EXTRACTABLE ORGANICS[a]

Parameter	Concentration, mg/L
Base/Neutral Extraction Fraction	
C_2-Pyridine	3.3
C_3-Pyridine	4.0
C_4-Pyridine	4.2
Phenol and isomers of phenol	35
Methyl cyclopentenone	2.2
Benzenamine	1.55
C_3-cyclohexen-1-one	1.45
Aziridine, ethylmethyl (isomer)	NP[b]
Pyrrolidinone, cyclohexylmethyl	NP[b]
Pyridinedicarbonitrile	4.6
C_3-piperidinium bromide	0.6
Butenone, dimethylamino (isomer)	0.7
Methyl quinoline or methyl isoquinoline	3.5
Cyclohexadienedione, tetramethyl	1.8
Pyrrole, methylphenyl	1.4
C_2-quinoline (isomer)	1.3
Unknown	47
Acid Extraction Fraction	
Unknown carboxylic acid	56
Unknown	34.4
Benzoic acid, methyl (isomer)	4.0
Benzene acetic acid	3.2
Benzene propanoic acid	0.5
Pyridinone, methyl (isomers)	0.1
Decanedioic acid	7.9
Furanone, ethyldihydromethyl	NP[b]

[a] One 24-hr composite sample taken on May 18, 1982.

[b] NP - not presented; no chromatographic peak was found for the sample.

Influent temperature ranged from 21°C to 46°C. Influent pH ranged from 8.6 to 9.4. The performance of filter coalescer is summarized in Table 9.

TABLE 8. RAW RETORT WATER CHARACTERIZATION - DOC FRACTIONS[a,b]

Parameter	Concentration, mg/L
Total DOC	2,280
Hydrophobic fraction	1,550
Acid	690
Base	100
Neutral	690
Unrecovered	70
Hydrophilic fraction	730
Acid	410
Base	60
Neutral	110
Unrecovered	150

[a] The DOC fractions represent the following compound categories:

Hydrophobic

Acid (aliphatic carboxylic acids C_5 to C_9; 1- and 2-ring aromatic carboxylic acids; 1- and 2-ring phenols; fulvic acid)
Base (1- and 2-ring aromatic amines except pyridine)
Neutral (hydrocarbons; aliphatic alcohols, amides, esters, ketones, and aldehydes $>C_5$; aliphatic carboxylic acids and aliphatic amines $>C_9$; aromatic carboxylic acids and aromatic amines of ≥ 3 rings)

Hydrophilic

Acid (aliphatic acids of $\leq C_5$, polyfunctional acids)
Base (aliphatic amines $\leq C_9$, amino acids, pyridine)
Neutral (aliphatic amides, alcohols, aldehydes, esters, and ketones $\leq C_5$; polyfunctional alcohols; carbohydrates.

[b] One 24-hr composite sample taken on May 18, 1982.

TABLE 9. FILTER COALESCER PERFORMANCE DATA SUMMARY[a]

Parameter	Influent, mg/L		Effluent, mg/L		Percent removal		Number of analyses performed
	Range	Average	Range	Average	Range	Average	
Oil and grease	51-170	113	50-170	107	0-18	6	5
TSS	27-93	59	20-90	47	0-43	21	8
VSS	23-78	54	21-58	42	6-37	20	5
Total COD	4,100-5,100	4,600	4,100-4,900	4,500	0-4	2	2
Total BOD_5	2,200-4,000	2,900	2,300-3,400	2,700	0-16	5	3

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[a] All samples were composites (taken over the duration of each run $\sim$8 hr) except for oil and grease samples (which were grab samples).

The filter coalescer on the average removed 6% of the residual oil and grease, 21% of the TSS, and 20% of the VSS. Organic removal associated with oil and grease removal was insignificant as indicated by the removals of total BOD_5 and COD, respectively. The raw retort water tested had already been through an oil/water separation step and insignificant BOD_5 and COD removals indicate the effectiveness of this initial treatment. In addition, the filter coalescer received raw retort water from the 23-m^3 (6,000-gal) supply tank (refer to Figure 10), which acted as a gravity oil/water separator. This explains the low oil and grease concentration in the raw wastewater and the resulting low oil and grease removal by the filter coalescer. Visual observations of the 23-m^3 (6,000-gal) supply tank confirmed oil floating on the surface. Hence, an oil/water separation step would be necessary in a retort water treatment scheme.

4.2.3 Flocculation/Clarification

The flocculator/clarifier was operated at 220 cm^3/s (3.5 gal/min) throuphput flow and at mixing energy (paddle rotation velocity) of 0.4 to 0.5 s^{-1} (24 to 30 RPM). Lime was added as a slurry through the flocculant addition port (refer to Figure 15) by a chemical metering pump and flocculator influent and clarifier effluent were analyzed using 8-hour composite samples. Flocculator influent and clarifier effluent pH ranged from 8.6 to 9.4.

Due to the presence of high alkalinity, low lime dosage (90 mg/L to 270 mg/L) resulted in insignificant contaminant removal as reported in Table 10. Lime dosages as high as 9,000 mg/L to 13,000 mg/L may be required to reduce high alkalinity levels and effect removals of settleable and/or floatable solids, metals, and fluorides from the oil/water separator effluent. Because of generally lower alkalinity levels in the stripper effluent, lime treatment of this effluent offers an alternative which could result in comparable treatment at lower lime dosage and consumption.

TABLE 10. FLOCCULATOR/CLARIFIER PERFORMANCE DATA SUMMARY[a]

	Lime dosage, mg/L					
	90		180		270	
	Concentration, mg/L		Concentration, mg/L		Concentration, mg/L	
Parameter	Influent	Effluent	Influent	Effluent	Influent	Effluent
TSS	22	22	-[b]	-[b]	23	21
Flourides	44	41	41	34	38	34
Chlorides	950	850	900	860	1,000	800
pH[c]	8.7	8.7	8.7	8.7	8.8	8.8
Ag	0.20	<0.18	<0.18	<0.18	-[b]	-[b]
Al	0.28	0.22	-[b]	-[b]	0.25	0.24
B	45	42	44	43	-[b]	-[b]
Ba	0.16	0.13	0.19	0.17	0.12	0.12
Be	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ca	3.0	3.3	3.5	15.2	3.6	13
Cd	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cr	0.04	0.03	0.04	0.03	0.04	0.04
Cu[d]	0.07	0.41	<0.04	0.3	0.09	0.45
Fe	0.74	0.65	-[b]	-[b]	0.69	0.68
K	225	191	223	214	-[b]	-[b]
Mg	2.6	2.3	2.9	2.9	-[b]	-[b]
Mn	0.01	0.01	0.01	0.01	0.01	0.01
Mo	1.5	1.3	-[b]	-[b]	1.38	1.35
Na	3,540	3,210	3,510	3,465	-[b]	-[b]
Ni	0.14	0.10	-[b]	-[b]	0.18	0.15
Pb	0.42	0.42	<0.42	<0.42	<0.42	<0.42
Sb	0.31	<0.27	<0.27	<0.27	0.30	<0.27
Sn	7.3	5.8	-[b]	-[b]	-[b]	-[b]
Sr	0.33	0.30	0.31	0.29	0.26	0.26
Ti	0.02	0.01	0.02	0.02	-[b]	-[b]
V	0.09	0.03	0.04	0.03	-[b]	-[b]
Zn	-[b]	-[b]	-[b]	-[b]	0.05	0.04

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[a] All samples were 8-hr composite except for pH analysis samples.

[b] Corresponding influent and effluent analyses gave inconclusive results.

[c] pH is in standard pH units.

[d] The increase in the effluent copper concentration is significant; cause of this increase in unknown.

4.2.4 Steam Stripping

The effluent from flocculator/clarifier was fed without pH adjustment into the steam stripper. Unavailability of cooling water at the Logan Wash test site did not permit use of the stripper overhead condenser. Hence, the stripper overhead stream was vented to the atmosphere and no data on this stream are available.

Steam stripping was performed to evaluate the removal of ammonia and alkalinity at various steam/liquid (G/L) ratios. During testing, the steam stripper was operated at a constant liquid feed rate of 190 cm^3/s (3 gal/min), and steam feed rates were varied to achieve the desired G/L ratios. The stripper was operated a minimum of 24 hours at each condition.

Other relevant parameters were monitored to observe incidental concentration changes of TKN, sulfide, DOC, soluble COD, soluble BOD_5, phenols, and cyanide. Samples of stripper liquid feed and effluent (bottoms) were analyzed for these parameters to determine their degree of removal. The stripper performance data, which summarize stripper feed and bottom concentrations for conventional pollutants, are presented in Table 11. Data on organics by GC/MS, DOC fractions, and metals data for the stripper feed and bottoms are presented in Tables 12 through 14, respectively, for a constant G/L ratio of 180 kg of steam per cubic meter of feed water (1.5 lb steam per gallon feed water). Percent ammonia and alkalinity removals as a function of G/L ratio are displayed in Figure 24.

Review of conventional pollutant data (Table 11) show that ammonia and alkalinity are readily stripped from retort water. As the G/L ratio increases, the degree of removals of these two pollutants also increases as expected. Greater than 97% ammonia removal and 47% alkalinity removal were achieved with G/L ratios equal to or greater than 180 kg of steam per cubic meter of feed water (1.5 lb steam per gallon feed water). TKN and ammonia removals increase

TABLE 11. STEAM STRIPPER PERFORMANCE DATA SUMMARY - CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS[d]

	G/L ratio, kg/m³ (lb/gal)														
	60 (0.6)			130 (1.1)			180 (1.5)			230 (1.9)			300 (2.5)		
	Concentration, mg/L			Concentration, mg/L			Concentration, mg/L			Concentration, mg/L			Concentration, mg/L		
Parameter[e]	Feed	Bottoms	Percent removal	Feed	Bottoms	Percent removal	Feed	Bottoms	Percent removal	Feed	Bottoms	Percent removal	Feed	Bottoms	Percent removal
NH_3-N	2,000	700	65	2,000	440	78	1,800	51	97	1,800	7	>99	3,900	<5	>99.9
TKN	2,200	620	71	2,100	510	76	1,700	210	88	1,920	180	91	3,000	160	95
Alkalinity as $CaCO_3$ to pH 4.5	15,000	10,000	32	15,000	8,800	40	13,000	7,000	47	12,000	5,300	57	17,000	4,500	73
Sulfide	86	0.6	99	50	0.5	99	-[a]	-	-	-	-	-	130	1.4	99
DOC	1,700	1,500	8	1,500	1,500	0	1,500	1,500	4	1,600	1,200	25	1,220	1,150	5
Soluble COD	-	-		-	-		-	-		-	-		5,400	4,500	16
Soluble BOD_5	2,200	2,000	9	2,000	1,800	11	2,000	1,900	5	-	-	-	-	-	-
Phenols	70	45	36	55	40	27	52	35	32	-	-	-	47	22	54
Cyanide	0.07	0.11	0	<0.02[b]	<0.02[b]	0	0.03	0.03	0	-	-	-	0.08	<0.02[b]	>75
pH[c]	8.8	9.3	NA	9.4	10.3	NA	8.7	9.6	NA	8.6	9.8	NA	8.7	9.9	NA

NA - Not applicable.

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[a] Data unavailable.

[b] Below detection limit.

[c] Standard pH units.

[d] Constant liquid feed of 190 cm³/s (3 gal/min).

[e] Results based on one composite sampled collected per run, except for phenols, cyanide, and pH were grab samples.

TABLE 12. STEAM STRIPPER PERFORMANCE DATA - ORGANICS[a]
(May 12, 1983)

Organic compound	Concentration, mg/L Feed	 Bottoms
Base/Neutral Extraction Fraction		
C_2-Pyridine	3.3	NP[b]
C_3-Pyridine	4.0	NP
C_4-Pyridine	4.2	NP
Phenol and isomers of phenol	35	31
Methyl cyclopentenone	2.2	2.2
Benzenamine	1.5	NP
Butenone, dimethylamino (isomer)	0.7	2.6
C_3-cyclohexen-1-one	1.4	1.0
Aziridine ethylmethyl (isomer)	NP	2.4
Pyrrolidinone, cyclohexylmethyl	NP	1.0
Pyridinedicarbonitrile	4.6	1.3
C_3 Piperidinium bromide	NP	2.0
Butenone, dimethylamino (isomer)	0.7	NP
Methyl quinoline or methyl isoquinoline	3.5	NP
Cyclohexadiene-dione, tetramethyl	1.8	1.5
Pyrrole, methylphenyl	1.4	NP
C_2-Quinoline (isomer)	1.3	NP
Unknown	46	39
Acid Extraction Fraction		
Unknown carboxylic acid	56	32
Unknown	34	86
Benzoic acid, methyl (isomer)	4.0	3.3
Benzene acetic acid	3.2	4.5
Benzene propanoic acid	0.5	NP
Pyridinone, methyl (isomers)	0.1	NP
Decanedioic acid	7.9	NP
Furanone, ethyldihydromethyl	NP	0.6
Total organics	216	210

[a] G/L ratio of 180 kg of steam per cubic meter of feed water (1.5 lb steam per gallon feed water).

[b] NP - not present; no chromatographic peak was found for the sample.

TABLE 13. STEAM STRIPPER PERFORMANCE DATA - METALS[a]

(May 12, 1983)

	Concentration, mg/L	
Metal	Feed	Bottoms
Ag	<0.18	0.34
Al	0.22	0.19
As	4.9	4.9
B	37	39
Ba	0.14	0.13
Be	<0.01	<0.01
Ca	4.3	5.2
Cd	0.01	0.02
Co	<0.06	0.06
Cr	0.05	0.05
Cu	0.05	0.22
Fe	0.65	0.57
K	170	190
Mg	2.3	1.8
Mn	0.01	0.02
Mo	1.2	1.4
Na	2,900	3,000
Ni	0.15	0.18
Pb	<0.42	<0.42
Sb	<0.27	0.27
Se	0.04	0.04
Sn	5.3	8.1
Sr	0.29	0.26
Ti	<0.08	<0.08
V	0.07	0.08
Zn	0.09	0.08

[a] G/L ratio of 180 kg of steam per cubic meter of feed water (1.5 lb steam per gallon feed water).

as the G/L ratios increase. Virtually similar TKN and ammonia values indicate TKN to be all ammonia. Sulfide is readily removed (>99%) at G/L ratios as low as 60 kg steam per cubic meter of feed water (0.6 lb steam per gallon feed water). Significant amounts of phenols, 27 to 54%, also were strippable, and the removals appear to depend on both G/L ratio and feed phenols concentration. Incidental removals of organics occurred.

TABLE 14. STEAM STRIPPER PERFORMANCE DATA - DOC FRACTIONS[a] (May 12, 1983)

Parameter/fraction	Concentration, mg/L		% Removal	Fraction distribution, %	
	Feed	Bottoms		Feed	Bottoms
Total DOC	2,280	1,930	15		
Hydrophobic fraction	1,550	1,250	19	68	65
Base	100	65	35	7	5
Acid	690	640	7	45	51
Neutral	690	540	22	45	43
Unrecovered	70	5	3	3	1
Hydrophilic fraction	730	680	7	32	35
Base	60	110	(83)[b]	8	16
Acid	410	510	(24)	56	75
Neutral	110	35	68	15	5
Unrecovered	150	25		21	4

[a] G/L ratio of 180 kg of steam per cubic meter of feed water (1.5 lb steam per gallon feed water).

[b] Number in bracket indicate increase.

Removals ranged from 0 to 25% for DOC, 5 to 11% for soluble BOD_5, and 16% for COD at the G/L ratios tested. Organics in retort water are relatively nonvolatile; therefore, high organics removals by steam stripping were not expected. The pH of the stripper bottoms was higher than that of the feed by 0.5 to 1.2 units. The pH was affected by ammonia and alkalinity removals. Ammonia removal decreased pH while alkalinity removal increased the pH.

Organic compounds data (Table 12) show that about 63% of the organic compounds in the feed water and 75% of the organic compounds in the stripper bottoms were unidentifiable owing to the complexity of the matrix in which they were present. Also, only 3% of the organics were removed by steam stripping. Phenols constituted about 16% and 15% of the organics in the stripper feed and bottoms, respectively. GC/MS analysis showed about 10% phenols

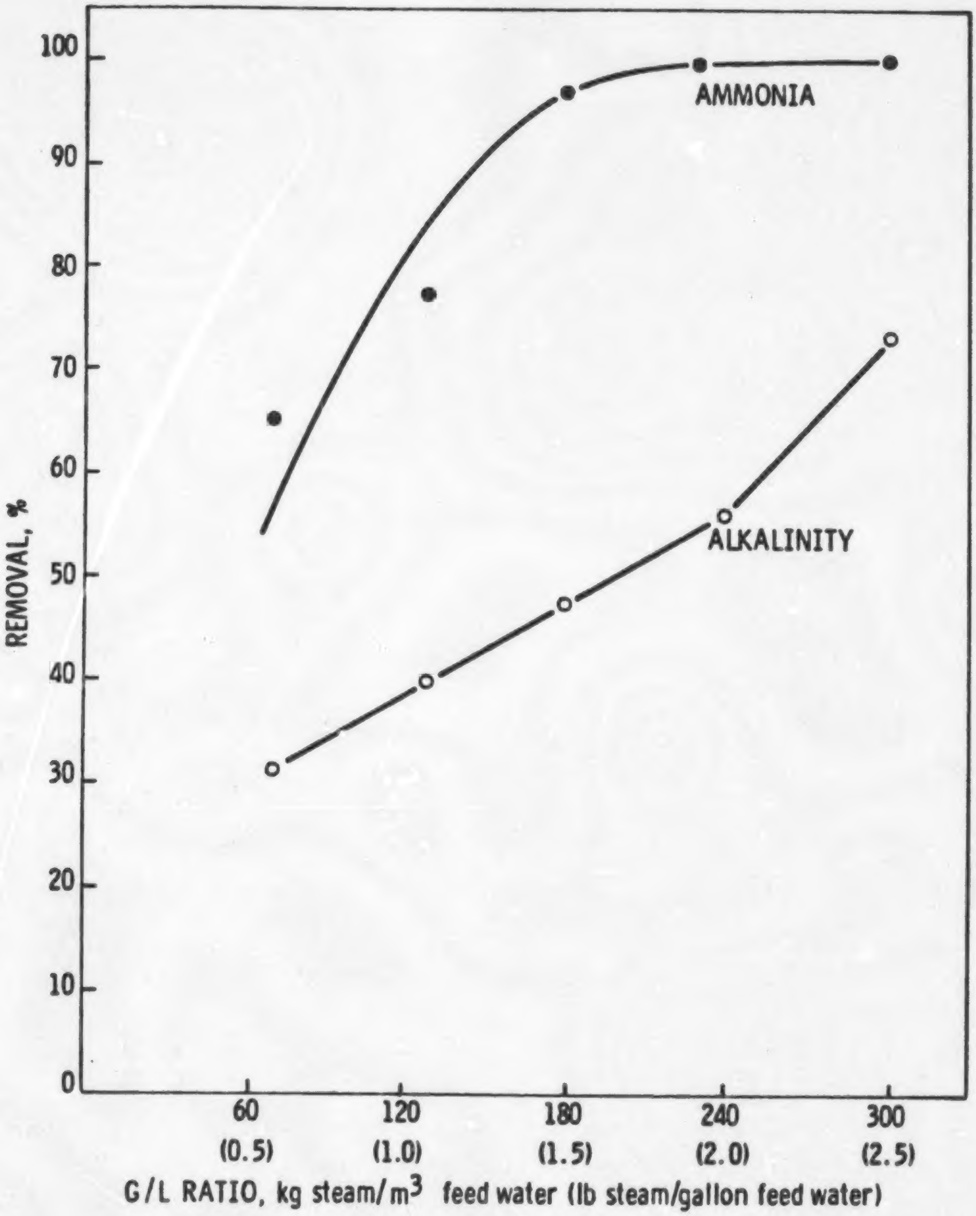

Figure 24. Percent removals of ammonia and alkalinity in steam stripper at various G/L ratios.

removal compared to 32% removal reported in Table 13 at a G/L ratio of 180 kg steam per cubic meter of feedwater (1.5 lb steam per gallon feed water).

Metals concentrations (Table 13) in the stripper feed and bottoms did not change significantly, as expected, because metals are nonvolatile.

Fractionation data (Table 14) show that 15% of the DOC was removed by the steam stripper. Removal of hydrophobic compounds was 19%, while hydrophilic compound removal was 7% (refer to Table 8 for a list of compounds represented by each fraction). Although the percentages of hydrophobic and hydrophilic compounds in the feed and bottoms did not change significantly, the acid, base and neutrals present in each catagory changed significantly, as can be seen in the fraction distribution percentage columns in Table 14. This suggests that perhaps the organics in the retort water are reactive and undergo chemical changes when exposed to the elevated temperatures and steam inside the stripper.

Attempts were made to obtain performance data at various G/L ratios and constant liquid feedrates of 190 cm^3/s (3 gal/min) and 380 cm^3/s (6 gal/min) using raw retort water as feed. Because of partial clogging of the overhead vapor lines with condensed ammonium carbonate these attempts were unsuccessful. The clogging increased the pressure across the stripper column and eventually led to column flooding. Steam cleaning of the column improved the column performance but did not increase the column throughput capacity to the desired 380 cm^3/s level. Unless condensate continually flushes out the ammonium carbonate and prevents build up and clogging of the stripper overhead line, use of the steam stripper for retort water treatment on a continuous basis may not be practically feasible.

4.3 GAS CONDENSATE TEST RESULTS

Gas condensate testing was performed May 22, 1982 through August 26, 1982. In general, the treatment units were operated continuously 24 hours a day. For each treatment unit, the parameters listed in Table 15 were monitored on a periodic basis by the operating personnel and entered into the equipment operation log book once every two hours. Samples of the influent and effluent were collected in accordance with the schedule presented in Table 3. Presentation and discussion of the results follow.

4.3.1 Raw Wastewater Characterization

Raw wastewater was analyzed for conventional pollutants, metals, and organics (by GC/MS and DOC fractionation). The results of these analyses on samples collected during 14 weeks of gas condensate tests are summarized in Tables 16 through 19. Ammonia, alkalinity, and soluble COD results were also graphed, to show their variation in these parameters with time (see Figures 25 through 27). As expected, the treated gas condensate contained high concentrations of ammonia, TKN, organics, alkalinity, phenols, and sulfide. Forty-five percent of the organics were hydrophobic; the remainder were hydrophilic. The gas condensate also contained high concentrations of pyridine and phenolic compounds as shown in Table 17.

4.3.2 Oil/Water Separation

A filter coalescer was used for oil/water separation during the entire gas condensate test period. Its performance in removing oil was evaluated at influent flow rates ranging 220 to 250 cm^3/s (3.5 to 4.0 gal/min), temperatures ranging 26°C to 45°C, and influent pH ranging 8.3 to 8.7. The performance was determined by monitoring the oil and grease levels in both the influent and effluent, (see Table 20). Although removal was as high as 52%,

TABLE 15. MONITORED EQUIPMENT OPERATING PARAMETERS DURING GAS CONDENSATE TESTING

Filter coalescer

- Influent pH
- Influent temperature
- Influent flow

Steam stripper

- Column feed flow and temperature
- Steam flow and pressure
- Column bottoms flow and temperature
- Overhead flow and temperature
- Column temperature - top and bottom
- Column pressure - top and bottom
- Column level
- Stripper bottoms - ammonia (field kit[b])

Boiler

- Steam pressure
- Boiler water level
- Boiler feedwater tank level

Primary clarifier

- Influent pH and dissolved oxygen

Aeration basin

- Influent flow
- Aeration basin pH
- Air flow
- Aeration basin dissolved oxygen
- Agitator RPM
- Sludge wastage rate
- Nutrient addition

Secondary clarifier

- Overflow dissolved oxygen

(continued)

TABLE 15 (continued)

Multimedia filters
Effluent flow
Carbon adsorption columns
Effluent flow
Backwash module
Air flow Water flow

[a] pH recorded in a lab notebook, not in the log.

[b] Semiquantitative determination performed as needed to provide a quick test to estimate ammonia levels in stripper bottoms. CHEMetrics, Inc. Model AN-10 ammonia-nitrogen test kit was used for this determination. The kit contains Nessler's reagent which forms a colored complex with ammonia. The color intensity is indicative of ammonia concentration which is estimated by comparison of a sample with color standards of known concentrations.

the maximum removal obtained corresponded to 5.8 mg of oil removed per liter of gas condensate. This removal is insignificant and added essentially nothing to the overall treatment.

The raw gas condensate had an average 7 mg/liter of TSS and 5 mg/liter of VSS during the test period. Because these concentrations were insignificant, filter coalescer performance for these two parameters was not evaluated.

4.3.3 Steam Stripping

Three types of steam stripping tests were performed: (1) at various G/L ratios, (2) over an extended period to produce an effluent suitable for biological treatment with ammonia levels

TABLE 16. RAW GAS CONDENSATE CHARACTERIZATION FOR CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS

Parameter	Number of analyses performed	Concentration, mg/L[a]	
		Range	Average
Total COD	2	2,000-4,100	3,100
Soluble COD	37 (13)[b]	1,400-4,100	2,700
		(2,000-4,200)	(2,800)
Soluble BOD$_5$	8	600-1,000	800
DOC	33	500-1,400	890
Oil and grease	(13)	(1.8-76)	(18.6)
NH$_3$-N	40 (33)	6,100-14,000	9,000
		(4,800-11,000)	(8,200)
TKN	21	1,300-9,700	6,800
NO$_3$-N	16	0.3-3.0	1.1
Alkalinity as CaCO$_3$ to pH 4.5	27 (19)	21,000-37,000	31,000
		(22,000-40,000)	(31,000)
Sulfide	17	18-190	72
Phosphorus	6	<0.01-1.3	0.26
Cyanide	(4)	(<0.02-0.11)	(0.04)
Phenols	(21)	(70-150)	(120)
Fluorides	9	0.07-1.05	0.43
TSS	8	<5-14	7
VSS	8	<5-6	5
TDS	6	48-140	98
pH	(~560)	(8.3-8.7)	(8.5)
Temperature	(~560)	(26-45)	(34)

[a] Except for pH and temperature; pH is reported in standard pH units and temperature in °C.

[b] Data reported in parentheses pertain to grab samples; the remaining data pertain to 24 hr composite samples.

below 25 mg/liter, and (3) over an extended period to produce an effluent suitable for biological treatment with ammonia levels of about 100 mg/liter.

TABLE 17. RAW GAS CONDENSATE CHARACTERIZATION FOR PURGEABLE AND EXTRACTABLE ORGANICS[a]

Parameter	Concentration, mg/L
Base/Neutral Extraction Fraction	
Pyridine compounds and their isomers	100
Trichloromethane	3.2
Benzene	5.4
Cyclohexene	9.2
Methylcyclopentenone	2.6
Phenolic compounds and their isomers	150
Trimethylcyclohexenone	3.9
Quinoline and/or isoquinoline	2.9
1H-Indole or benzeneacetonitrile	2.1
Methyl quinoline or methyl isoquinoline	3.4
Unknown	67
Acid Extraction Fraction	
Trichloromethane	1.9
Benzene	4.2
Cyclohexene	10
Carboxylic acid	20
Phenols	1.1
Alkenes $\geq C_8$	0.81
Unknown	6.3

[a] One 24 hr composite sample taken on August 4, 1982.

The capability of the steam stripper to remove ammonia and alkalinity from filter coalescer effluent was evaluated first. The evaluations were performed at various steam/liquid (G/L) ratios with a constant liquid (filter coalescer effluent) feedrate of 190 cm^3/s (3 gal/min) and with no feed pH adjustment. Average bottoms rates were equal to feed rates of 190 cm^3/s (3 gal/min). Unavailability of cooling water at the Logan Wash test site did not permit use of the stripper overhead condenser. Hence, the stripper overhead stream was partially condensed to preheat stripper wastewater feed and the remainder vented to the atmosphere. Thus, no data on the overhead stream are available.

TABLE 18. RAW GAS CONDENSATE CHARACTERIZATION FOR METALS[a]

Parameter	Concentration, mg/L
Ag	<0.19
Al	0.20
As	<0.01
B	0.40
Ba	<0.01
Be	<0.01
Ca	1.91
Cd	<0.01
Co	<0.04
Cr	<0.02
Cu	<0.03
Fe	0.16
Hg	<0.01
K	<2.6
Mg	0.18
Mn	<0.01
Mo	<0.05
Na	10
Ni	<0.08
Pb	0.1
Sb	<0.01
Se	<0.01
Sn	<0.5
Sr	<0.01
Ti	<0.02
V	0.03
Zn	0.19

[a] One 24 hr composite sample taken on August 4, 1982.

TABLE 19. RAW GAS CONDENSATE CHARACTERIZATION FOR DOC FRACTIONS[a]

Parameter	Concentration, mg/L
Total DOC	482
Hydrophobic fraction	216
Acid	47
Base	96
Neutral	73
Hydrophilic fraction	266
Acid	17
Base	52
Neutral	197

[a] One 24-hr composite sample taken on August 4, 1982.

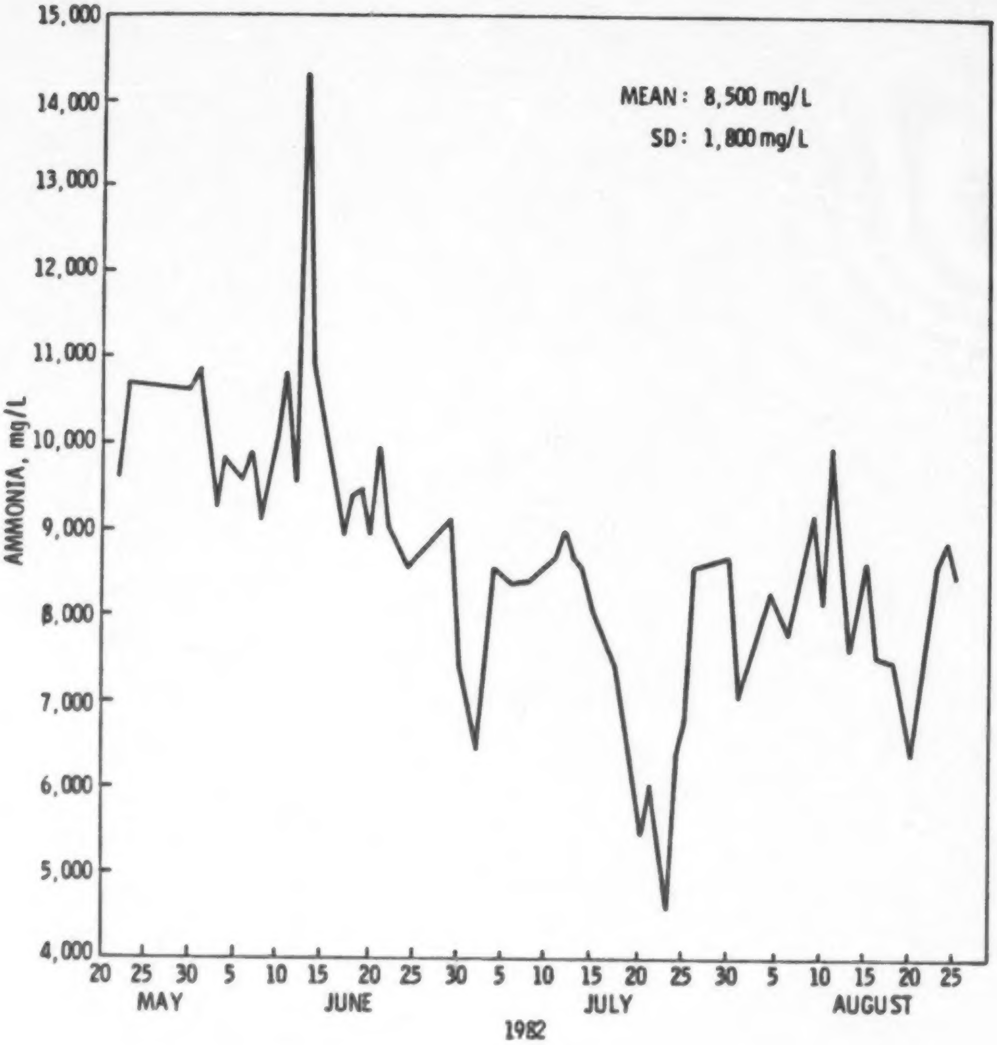

Figure 25. Raw gas condensate wastewater ammonia concentration variations (grab and composite sample results).

Although ammonia and alkalinity were the parameters of primary interest, other parameters such as soluble COD, DOC, sulfide, phenols, TKN, and pH were also monitored to observe any incidental removal or change. The results of these initial

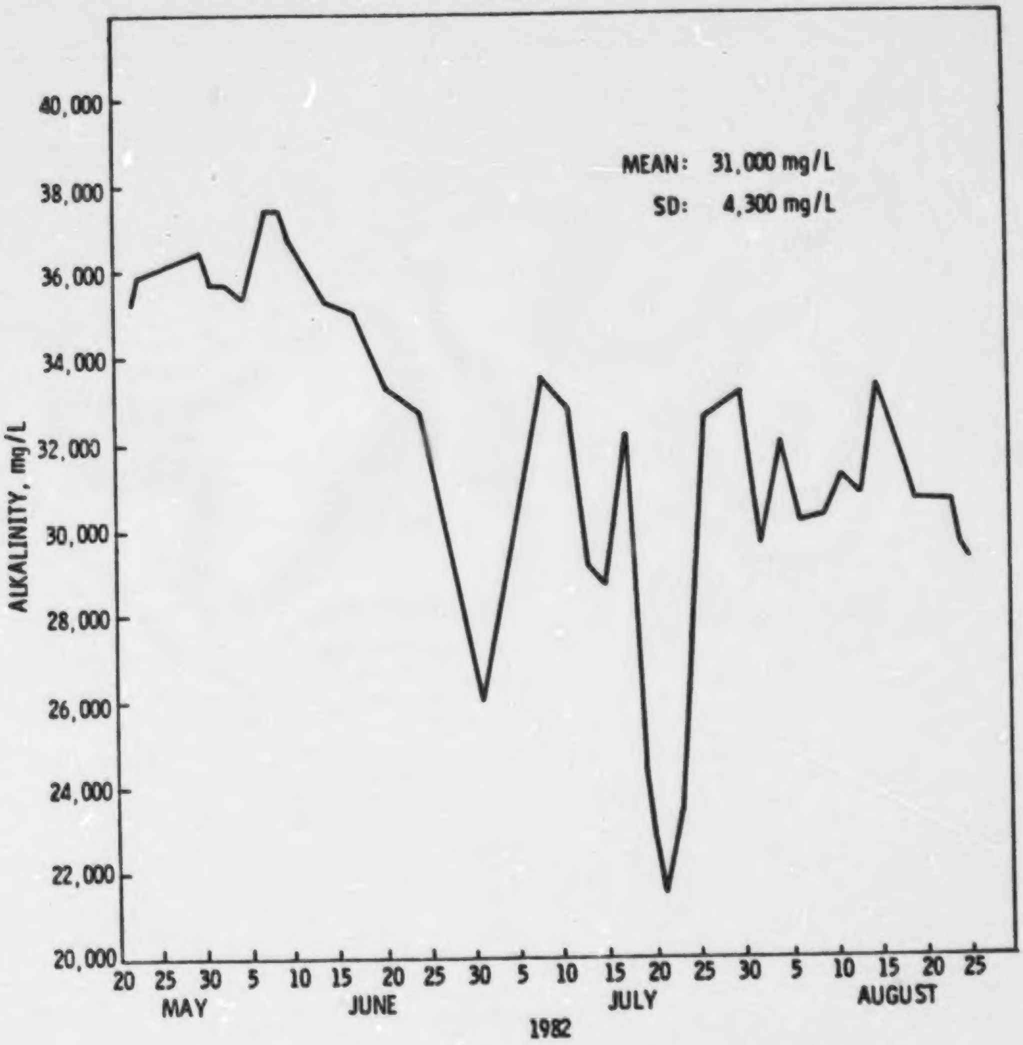

Figure 26. Raw gas condensate wastewater alkalinity concentration variations (as $CaCO_3$ to pH 4.5) (grab and composite sample results).

evaluations are summarized in Table 21. Ammonia, alkalinity, soluble COD, and DOC removals observed during these evaluations also are plotted as a function of varying G/L ratio in Figure 28 through 31.

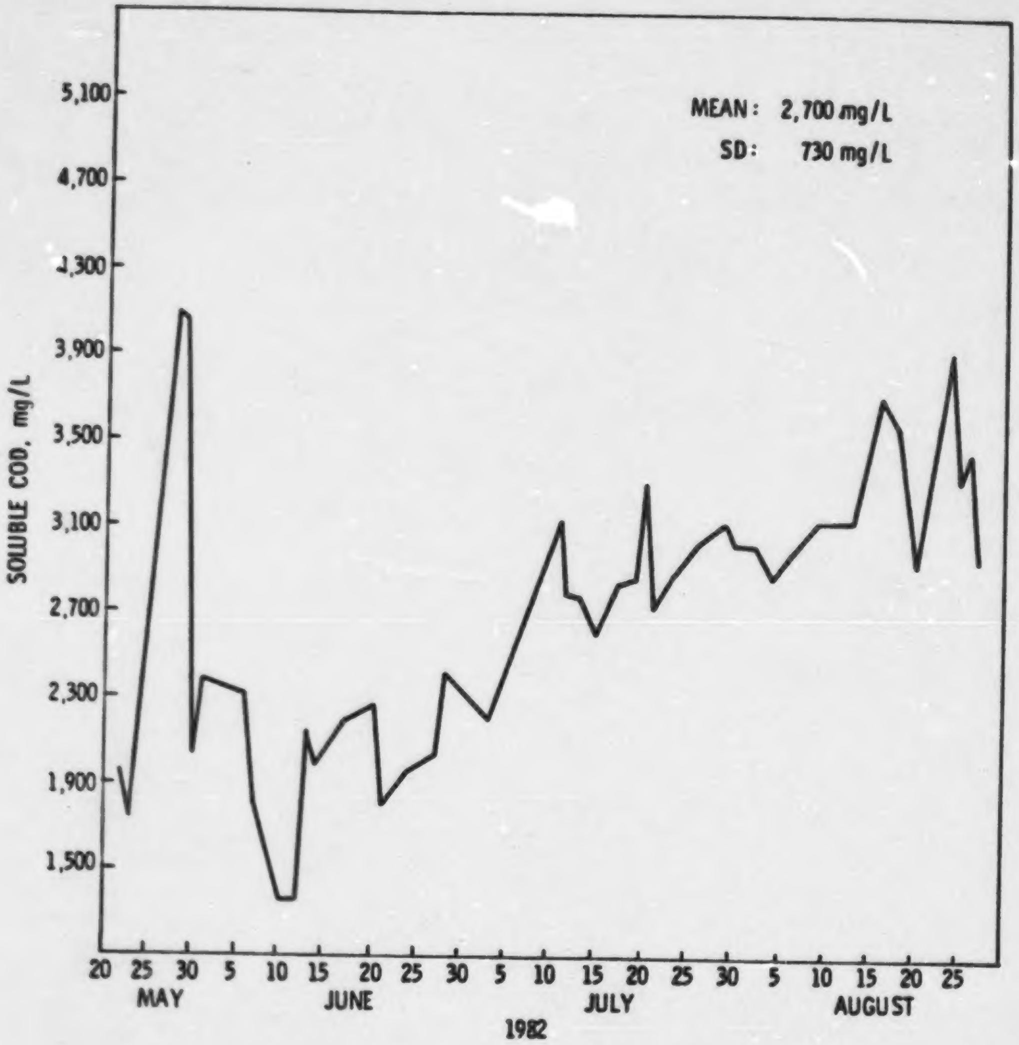

Figure 27. Raw gas condensate wastewater soluble COD concentration variations (grab and composite sample results).

A review of the initial results revealed that ammonia, alkalinity, sulfide, phenols, DOC, TKN, and COD could readily be stripped from gas condensate and that the removal efficiencies increased, as expected, with an increase in G/L ratio. Ninety-nine percent of both alkalinity and ammonia were removed at G/L ratios of 120 kg/m^3 (1 lb/gal) or higher. Ninety-nine percent of the sulfide

TABLE 20. FILTER COALESCER PERFORMANCE DATA SUMMARY - GAS CONDENSATE

Parameter	Influent concentration, mg/L		Number of analyses performed	Effluent concentration, mg/L		Number of analyses performed	Percent removal[a]	
	Range	Average		Range	Average		Range	Average
Oil and grease	1.8-76	18.6	13	1.0-24.3	8.6	5	0-52	28

[a] Based upon 5 pair of analyses.

TABLE 21. STEAM STRIPPER PERFORMANCE DATA SUMMARY FOR CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS - GAS CONDENSATE

Parameter[a]	G/L ratio, kg/m^3 (lb/gal)											
	60 (0.5)			120 (1.0)			150 (1.25)			180 (1.5)		
	Concentration, mg/L		Percent removal	Concentration, mg/L		Percent removal	Concentration, mg/L		Percent removal	Concentration, mg/L		Percent removal
	Feed	Bottoms		Feed	Bottoms		Feed	Bottoms		Feed	Bottoms	
NH_3-N	11,500	4,300	62	11,000	130	99	10,000	61	99	9,600	20	>99
TKN	9,700	2,800	71	9,700	210	98	3,100	750	76	2,700	47	98
Alkalinity as $CaCO_3$ to pH 4.5	36,000	14,000	62	36,000	350	99	36,000	220	99	35,000	88	>99
Sulfide	58	0.3	99	64	0.5	99	47	0.1	>99	38	<0.1	>99
DOC	750	210	72	770	90	88	850	96	89	710	100	86
Soluble COD	1,900	700	63	1,900	400	78	1,500	320	79	2,000	310	84
Phenols	88	45	49	77	35	55	83	42	49	69	31	55
pH[b]	8.6	10.1	NA	8.7	9.5	NA	8.7	9.8	NA	8.6	8.9	NA

NA - Not applicable.

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[a] Results based on one composite sample taken over duration of run except for phenols and pH, which were grab samples.

[b] Standard pH units.

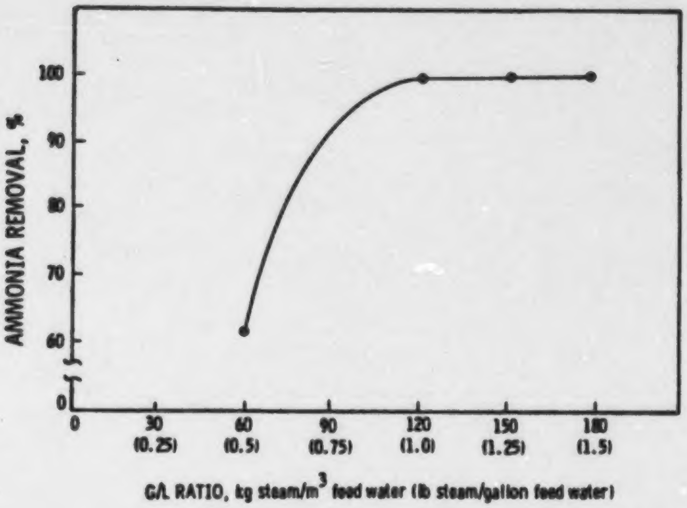


Figure 28. Percent ammonia, removal at various G/L ratios for gas condensate.

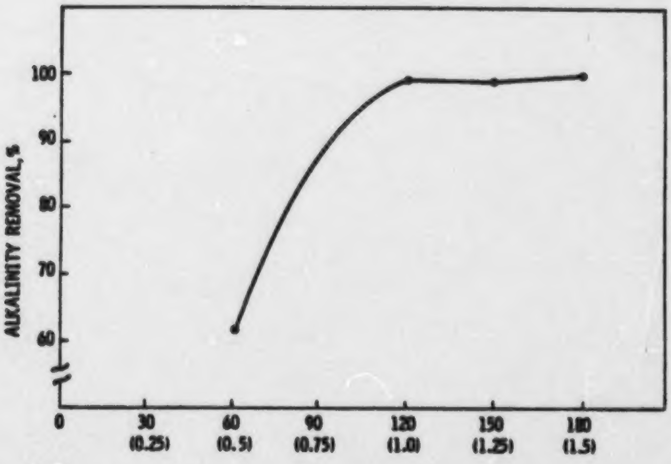


Figure 29. Percent alkalinity removal at various G/L ratios for gas condensate.

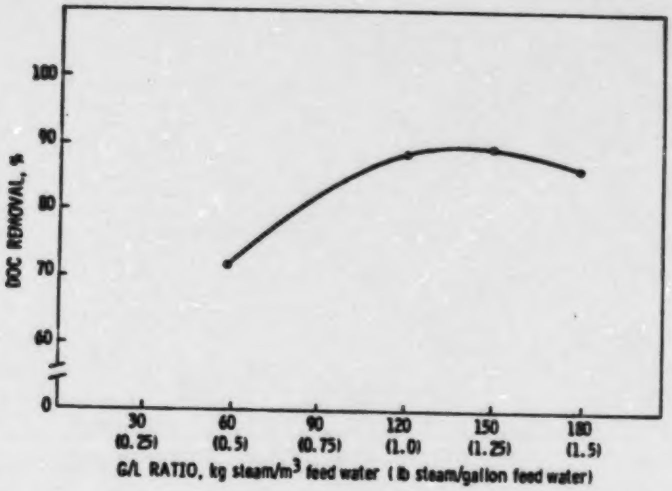


Figure 30. Percent DOC removal at various G/L ratios for gas condensate.

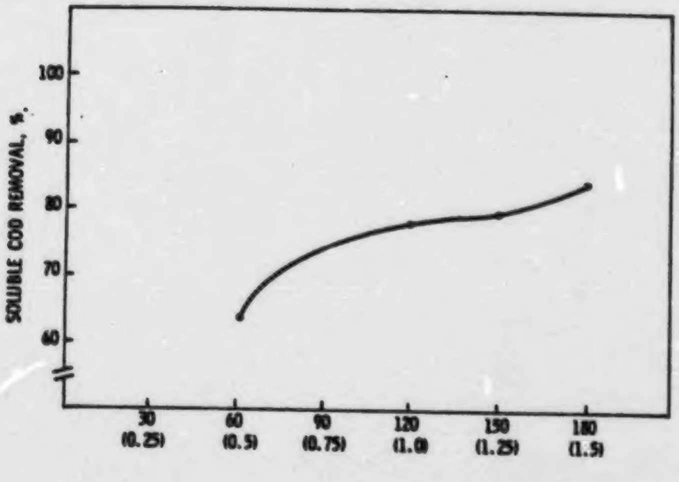


Figure 31. Percent soluble COD removal at various G/L ratios for gas condensate.

was removed at G/L ratios of 60 kg/m^3 (0.5 lb/gallon) or higher. Phenols removals were about 50% and were relatively independent of G/L ratio. More than 60% of the TKN, DOC, and soluble COD were removed at G/L ratios of 60 kg/m^3 (0.5 lb/gallon) or higher. The pH of the stripped effluent was always higher than that of the gas condensate feed.

The second type of stripper test comprised operation of the stripper for extended periods to produce an effluent for biological treatment. These tests were performed from May 26 to August 26, 1982. During that period, the biological treatability of pretreated gas condensate was being investigated. An effluent suitable for biological treatment was required to have an ammonia concentration that would not lead to poor COD removals during biological treatment as a result of inhibition by ammonia. Thus, from May 26 to June 10, 1982, the stripper was operated within a rather narrow range of operating conditions to produce an effluent with ammonia levels ranging from 10 to 32 mg/liter (see Table 22). However, at this level of ammonia the effluent contained only 210 to 510 mg/liter of soluble COD (down from 1,400 to 2,400 mg/liter in the raw gas condensate owing to incidental removal of COD in the stripper). This relatively low COD concentration in the effluent was increased to provide an increase in the amount of substrate for the biomass in the biological treatment (see Section 4.2.5). Therefore, for the remaining period, from June 11 to August 26, 1982, the stripper operation was adjusted to produce an effluent with an ammonia level from 46 to 180 mg/liter as the third type of stripper test . This led to a corresponding increase in COD level, of 470 to 2,100 mg/liter (see Table 23). Data showing variations in stripper operation (G/L ratio) and removals for ammonia, alkalinity, soluble COD, DOC, and phenols over the test period are plotted in Figures 32 through 36, respectively.

TABLE 22. SUMMARY OF STEAM STRIPPER PERFORMANCE FROM MAY 26 TO JUNE 10, 1982[a]

Parameter	Concentration, mg/L						Number of analyses performed
	Feed		Effluent		Percent removal		
	Range	Average	Range	Average	Range	Average	
NH_3-N	9,000-10,700	9,700	10-32	22	>99-100	100	12
TKN		7,800		140		98	1
Alkalinity as $CaCO_3$ to pH 4.5	35,000-40,000	37,000	30-1,500	320	96-100	99	8
Sulfide		68		0.9		99	1
DOC	500-520	510	89-99	94	89-99	94	2
Soluble COD	1,400-2,400	2,000	210-510	310	63-89	83	6[d]
Phenols		80		50		37	1[d]
Cyanide		0.11		<0.02		83	1[d]
pH	8.5-8.7[b]	8.6[b]	8.1-9.2[b]	8.7[b]	NA[c]	NA	44[d]

[a] Steam stripper operating conditions data summary:

G = steam flow rate, kg/s (lb/hr): range: 3.3×10^{-2} to 3.9×10^{-2} (260-300)
average: 3.9×10^{-2} (300)

L = liquid flow rate, cm^3/s (gal/min): 190 (3.0) (constant)

G/L = steam/liquid ratio, kg/m^3 (lb/gal): range: 180-200 (1.5-1.7)
average: 190 (1.6)

Feedwater temperature, °C (°F): range: 77-80 (171-176)
average: 79 (174).

[b] Standard pH units.

[c] NA = not applicable.

[d] Grab samples.

TABLE 23. SUMMARY OF STEAM STRIPPER PERFORMANCE FROM JUNE 11 TO AUGUST 26, 1982[a]

Parameter	Concentration, mg/L				Percent removal		Number of analyses performed
	Feed		Effluent				
	Range	Average	Range	Average	Range	Average	
NH_3-N	4,600-14,300	8,300	46-180	100	98->99	99	58
TKN	1,300-8,800	6,600	47-470	180	88-99	96	14
Alkalinity as $CaCO_3$ to pH 4.5	21,000-35,000	40,000	200-890	360	97-99	99	38
Sulfide	18-190	69	0.1-6	1.7	96->99	97	11
DOC	610-1,400	930	160-510	370	34-89	60	26
Soluble COD	1,800-4,200	2,900	470-2,100	1,300	36-78	56	35
Phenols	79-150	130	59-110	91	7-42	29	16
Cyanide	<0.02-0.91	0.32	<0.02-0.65	0.23			3[d]
NO_3-N	0.57-1.5	0.84	0.25-1.0	0.55			8[d]
pH	8.3-8.7[b]	8.5[b]	7.8-9.2[b]	8.6[b]	NA[c]	NA	462[d]

[a] Steam stripper operating conditions data summary:

G = steam flow rate, kg/s (lb/hr): range: 2.2×10^{-2} to 3.3×10^{-2} (170-260)
average: 2.5×10^{-2} (200)

L = liquid flow rate, cm^3/s (gal/min): range: 158-190 (2.5-3.0)
average: 183 (2.9)

G/L = steam/liquid ratio, kg/m^3 (lb/gal): range: 120-180 (1.0-1.5)
average: 150 (1.2)

Feedwater temperature, °C (°F): range: 68-88 (154-190)
average: 81 (178).

[b] Standard pH units.

[c] NA = not applicable.

[d] Grab samples.

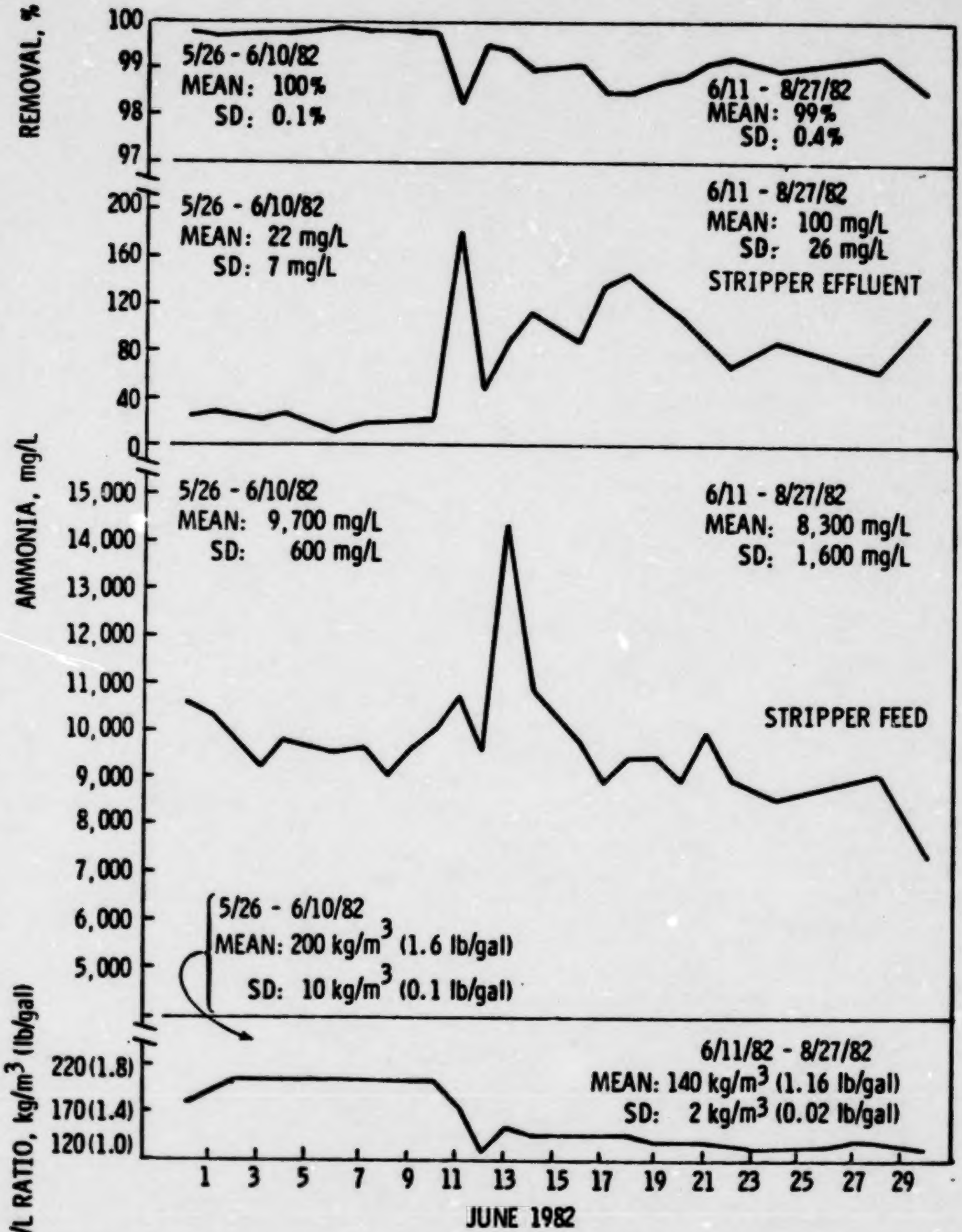


Figure 32. Long-term steam stripper performance - ammonia removals between June 1 - August 26, 1982.

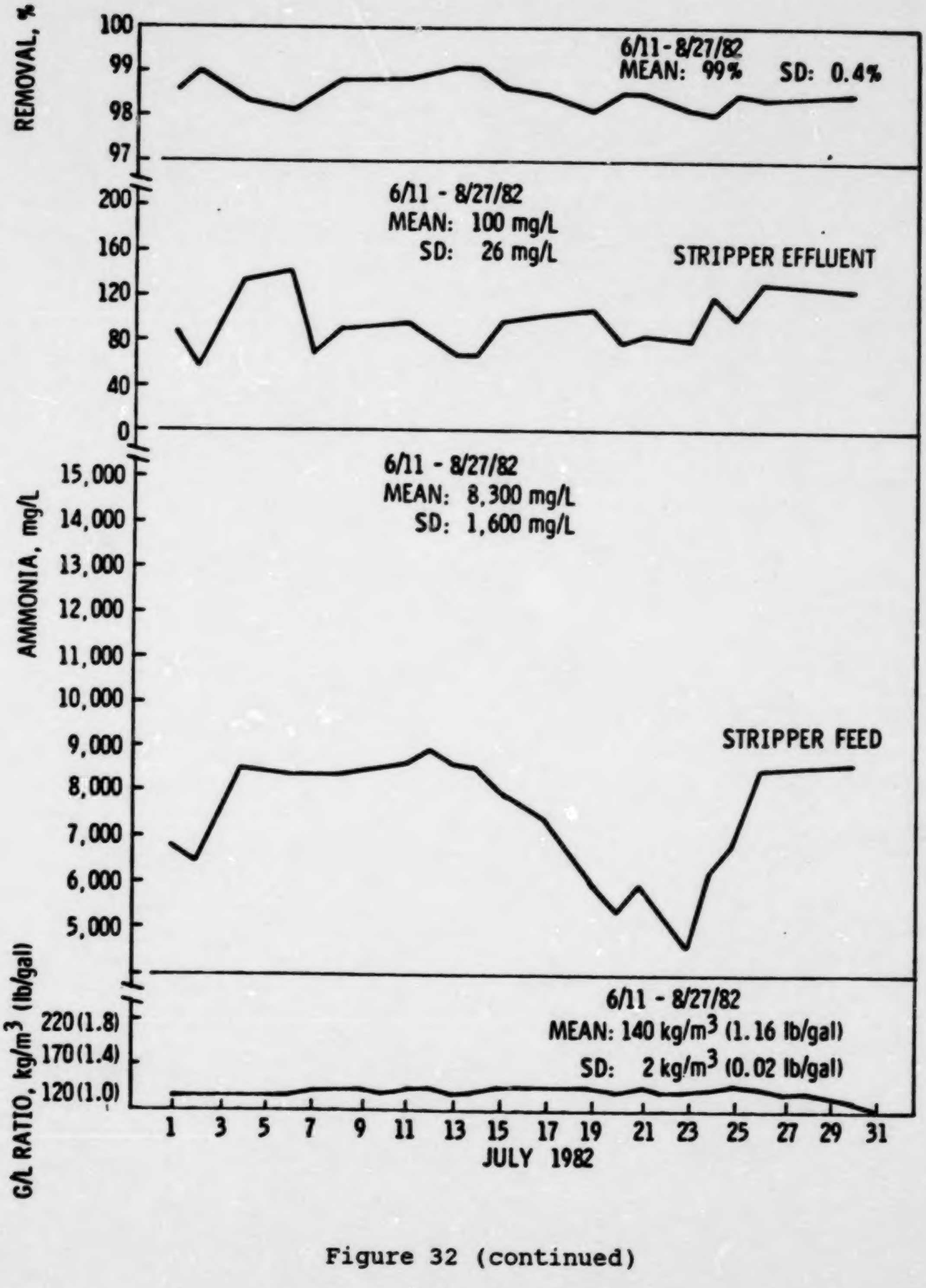


Figure 32 (continued)

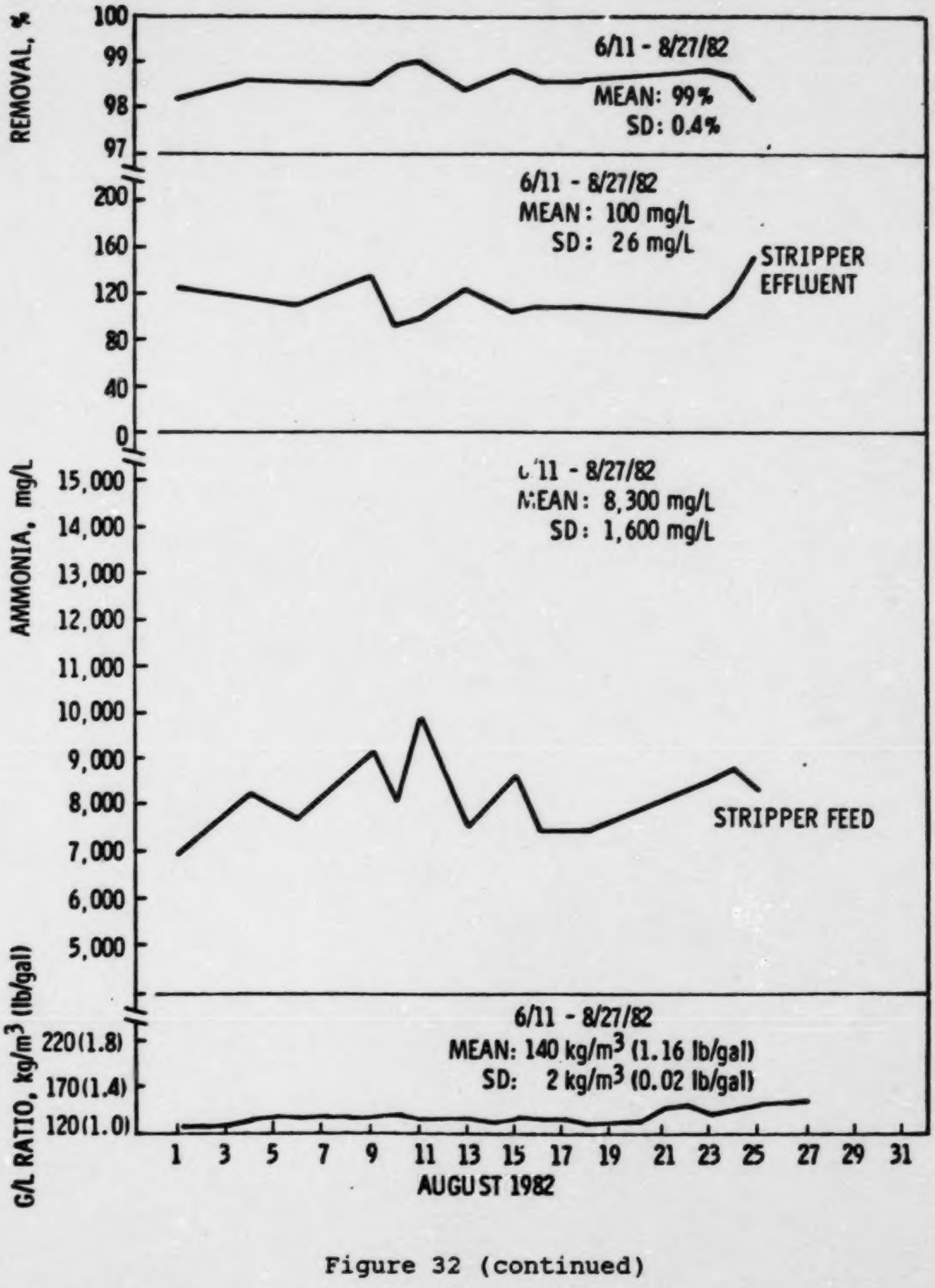


Figure 32 (continued)

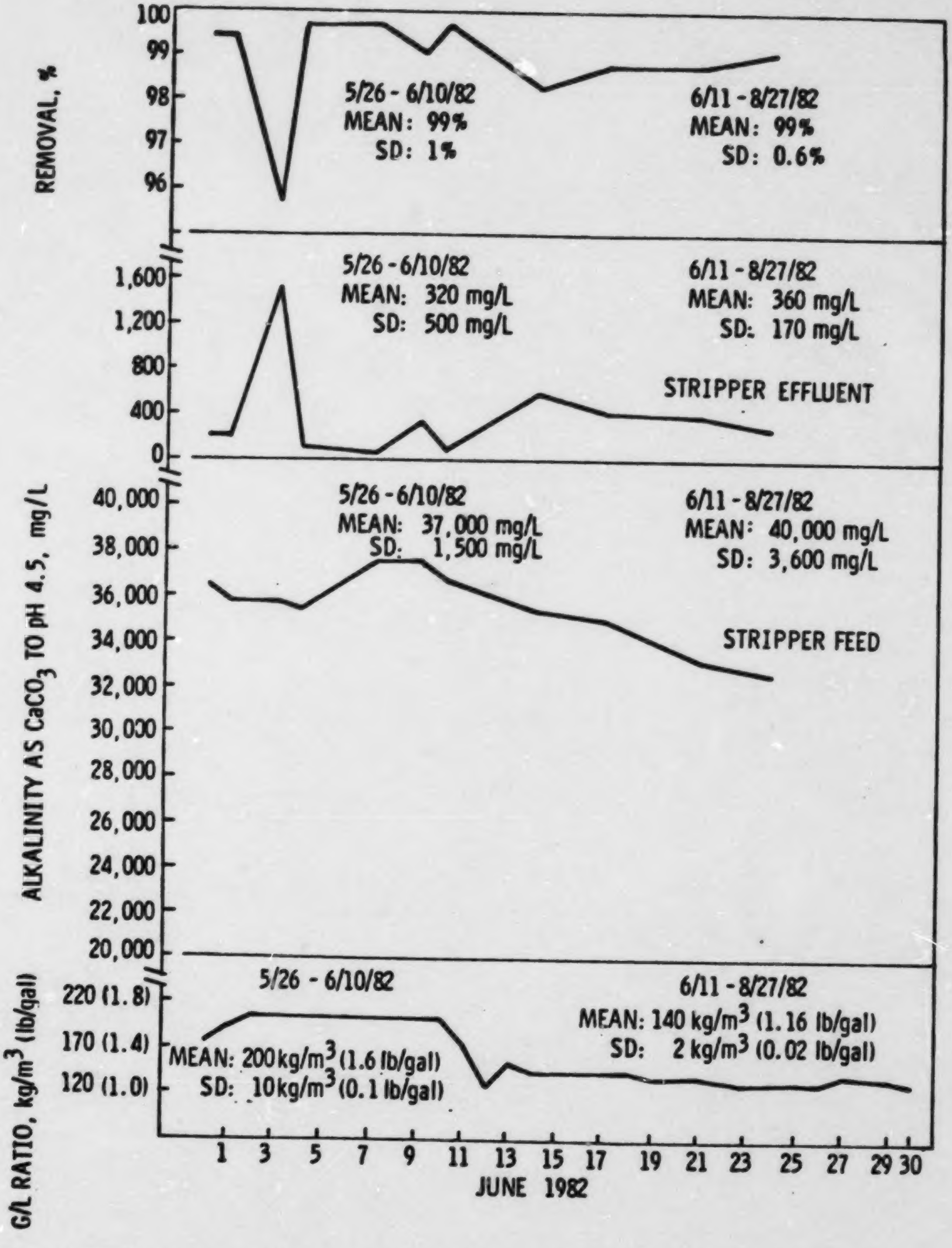
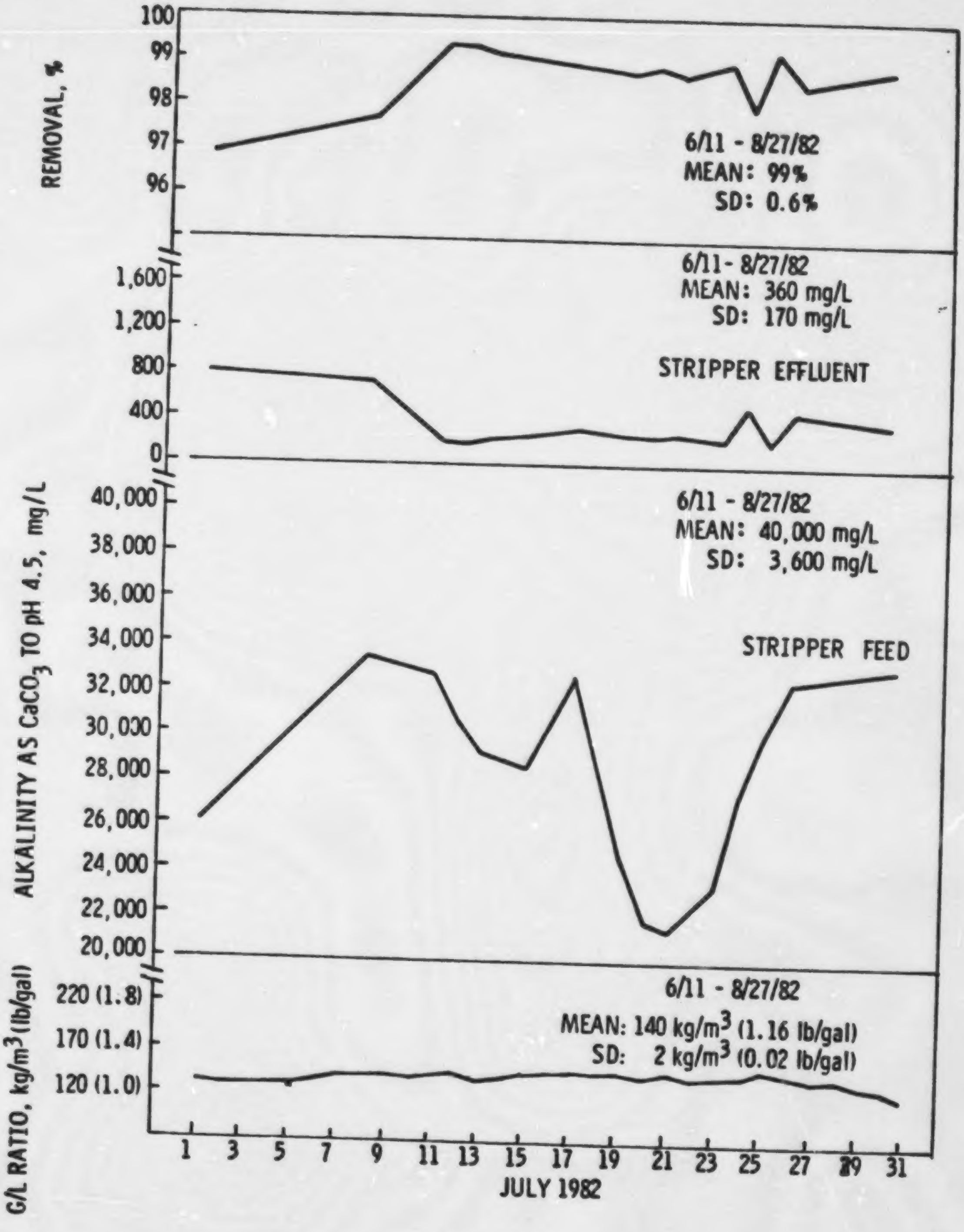


Figure 33. Long-term steam stripper performance - alkalinity removals between June 1 - August 26, 1982.



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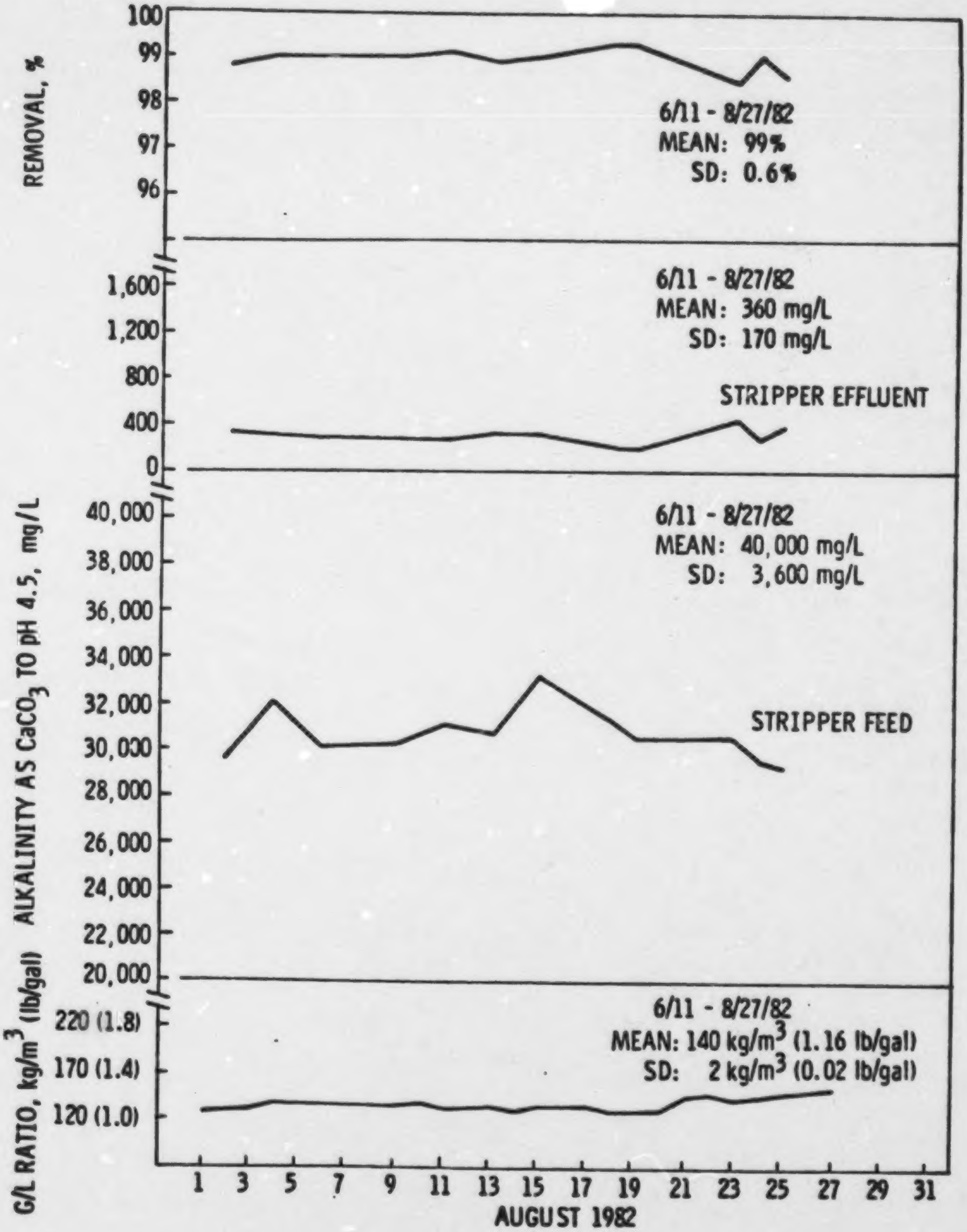

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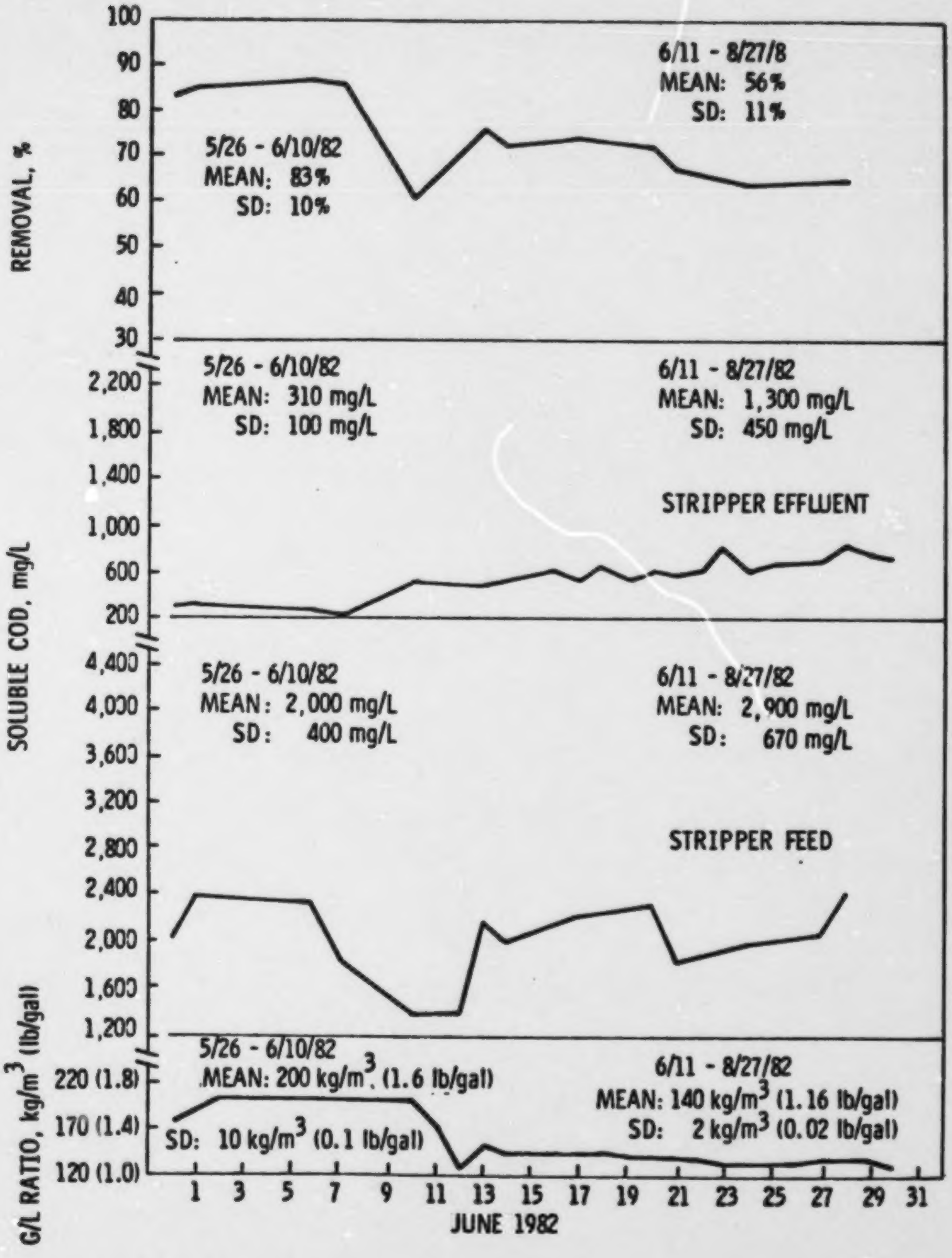
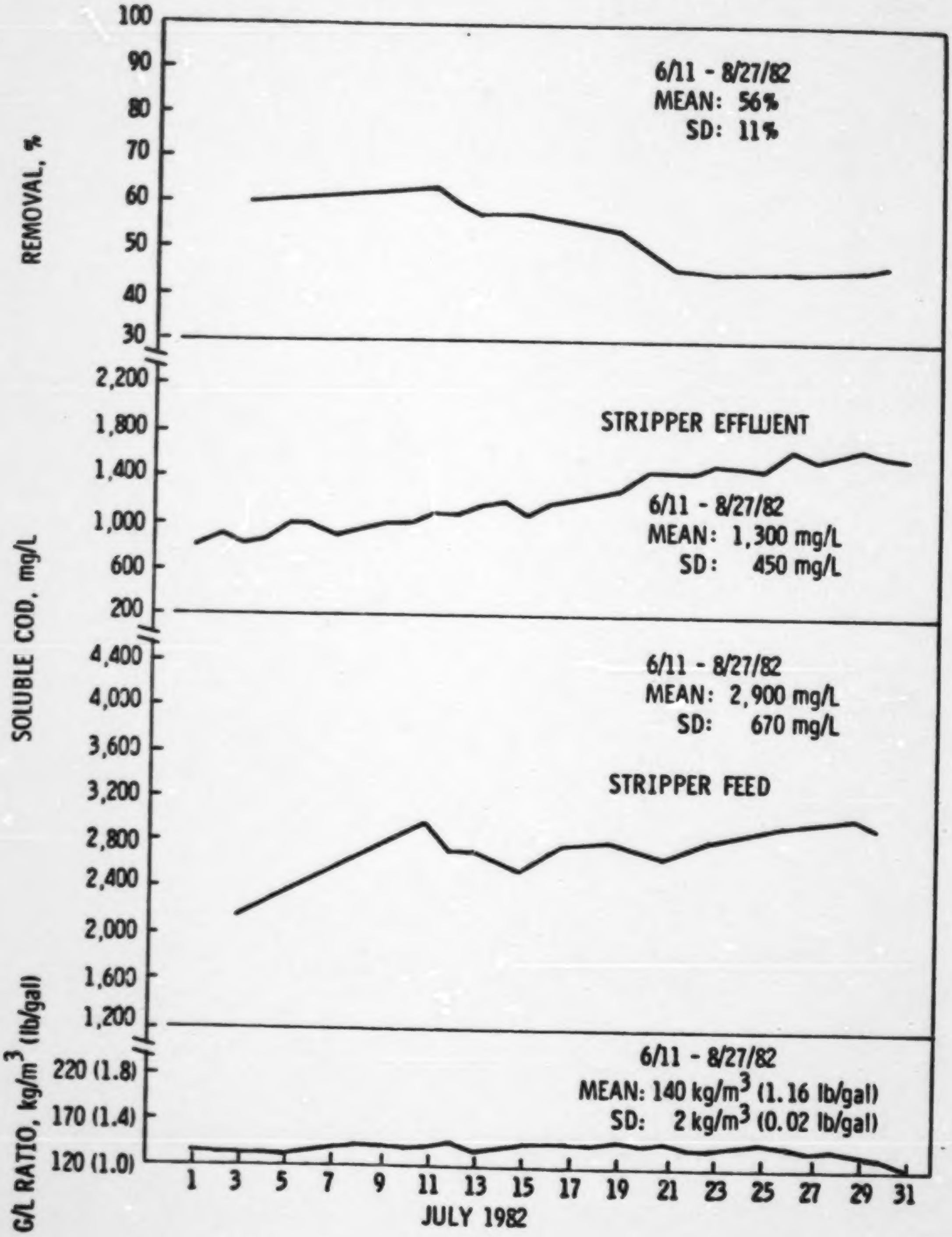


Figure 34. Long-term steam stripper performance - soluble COD removals between June 1, 1982 and August 26, 1982.



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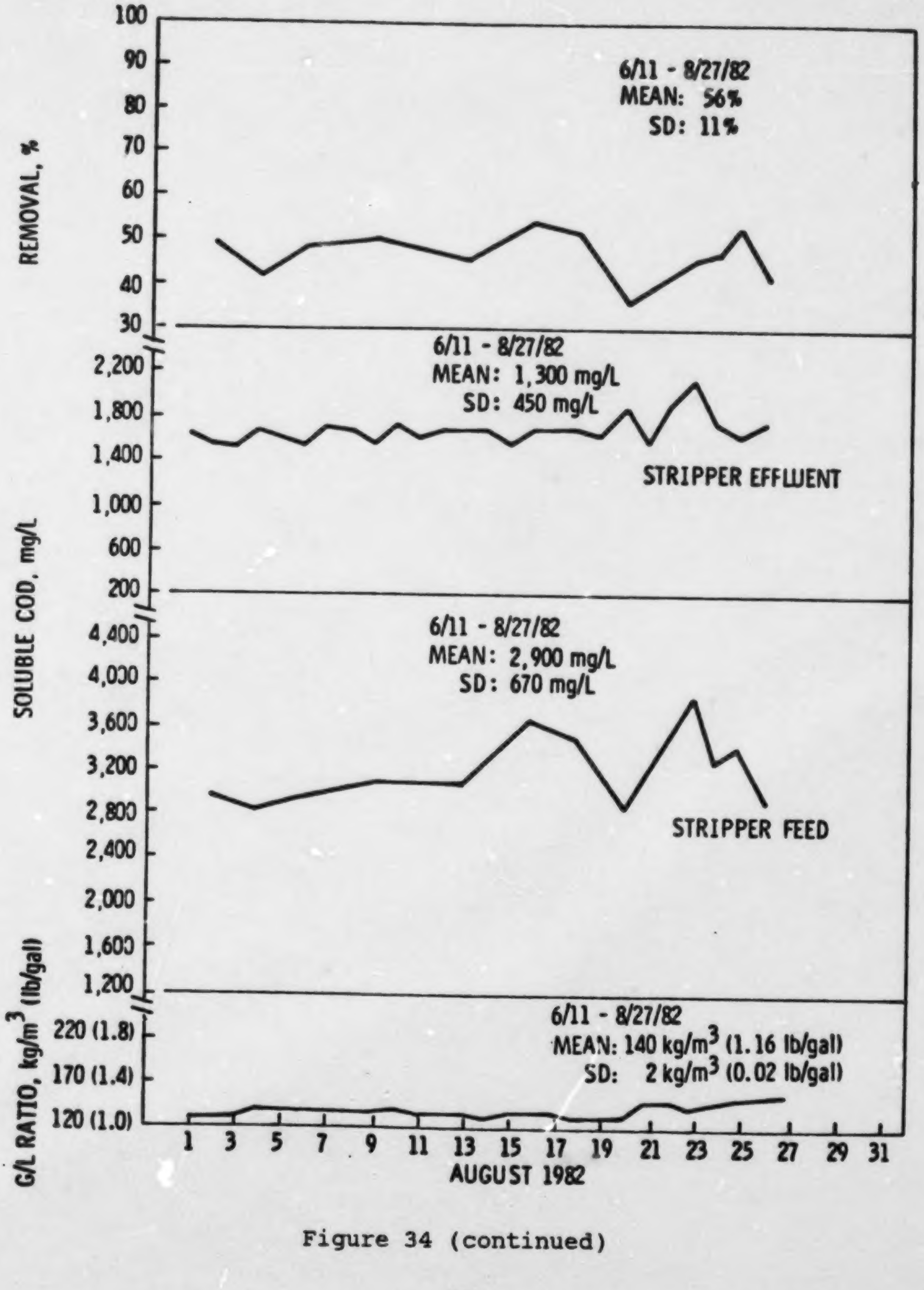

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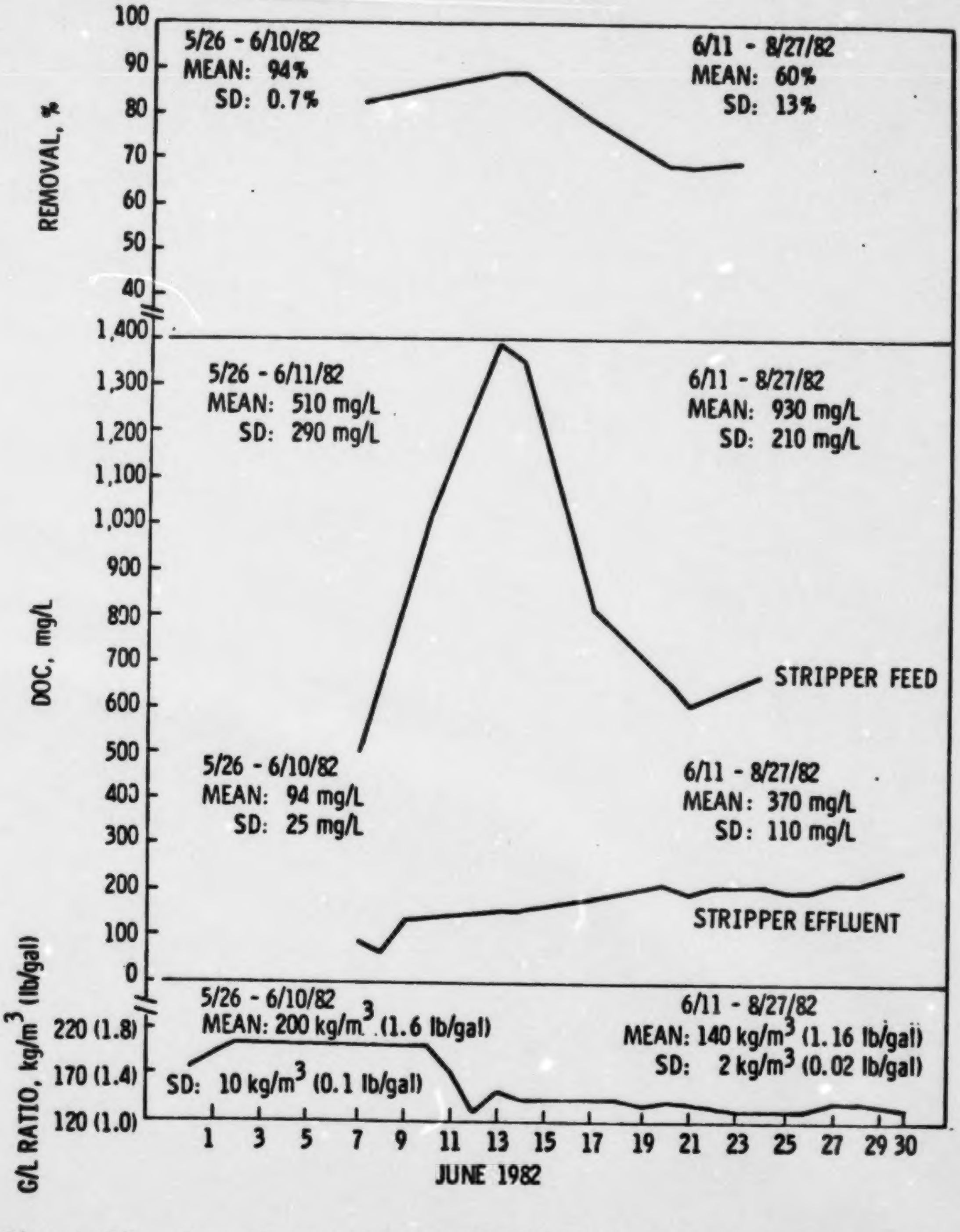
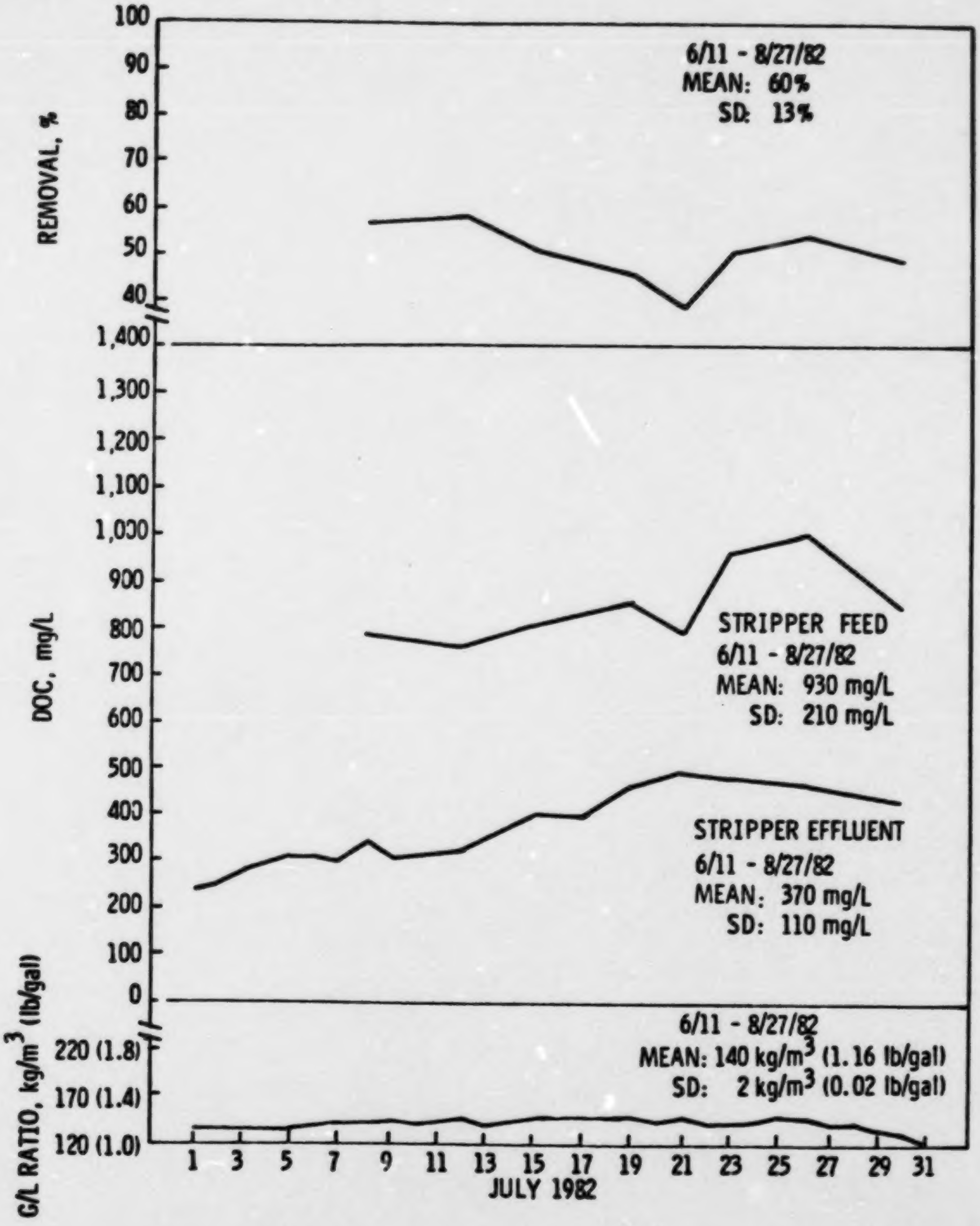


Figure 35. Long-term steam stripper performance - DOC removals between June 1, 1982 and August 26, 1982.



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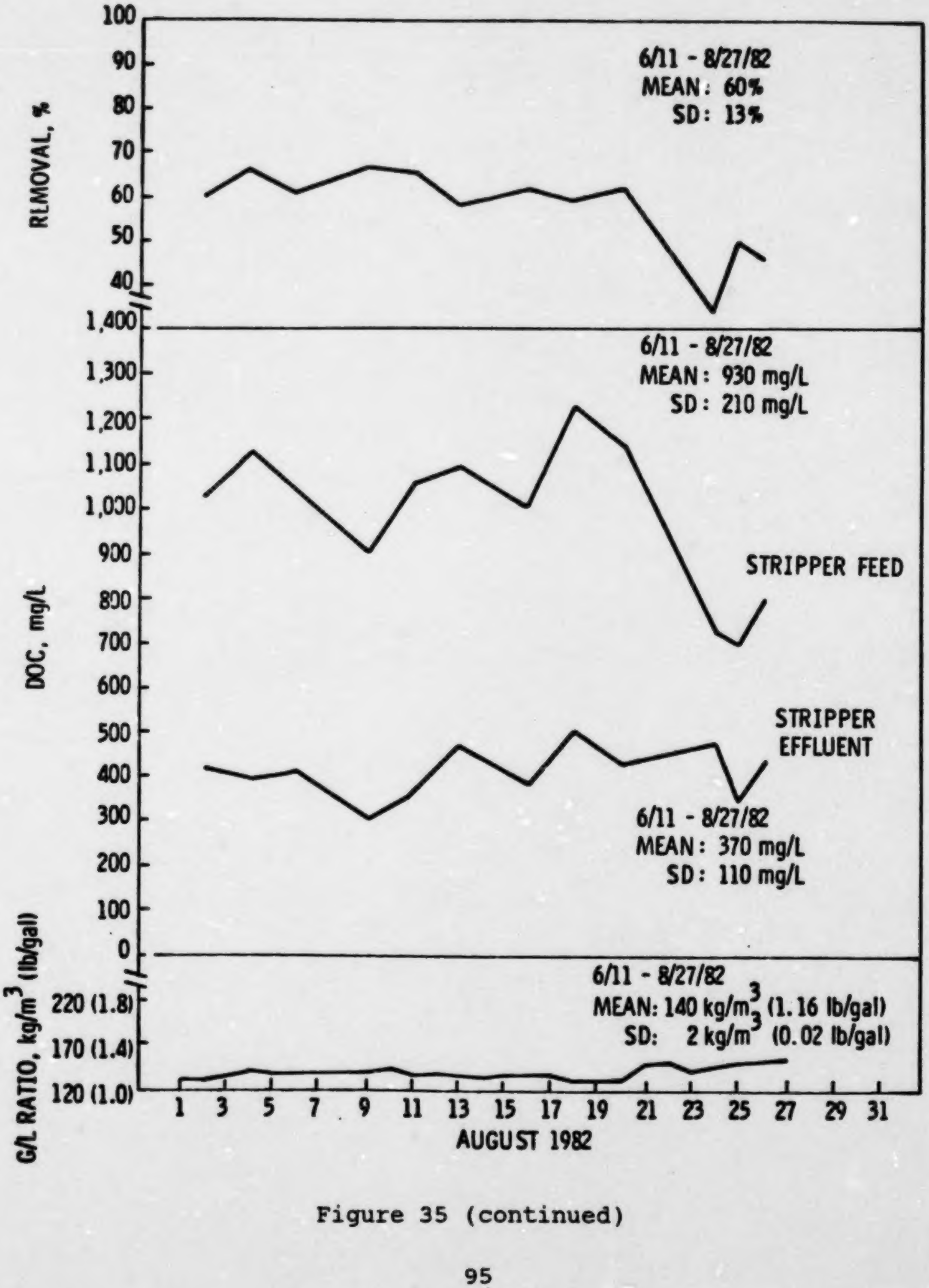

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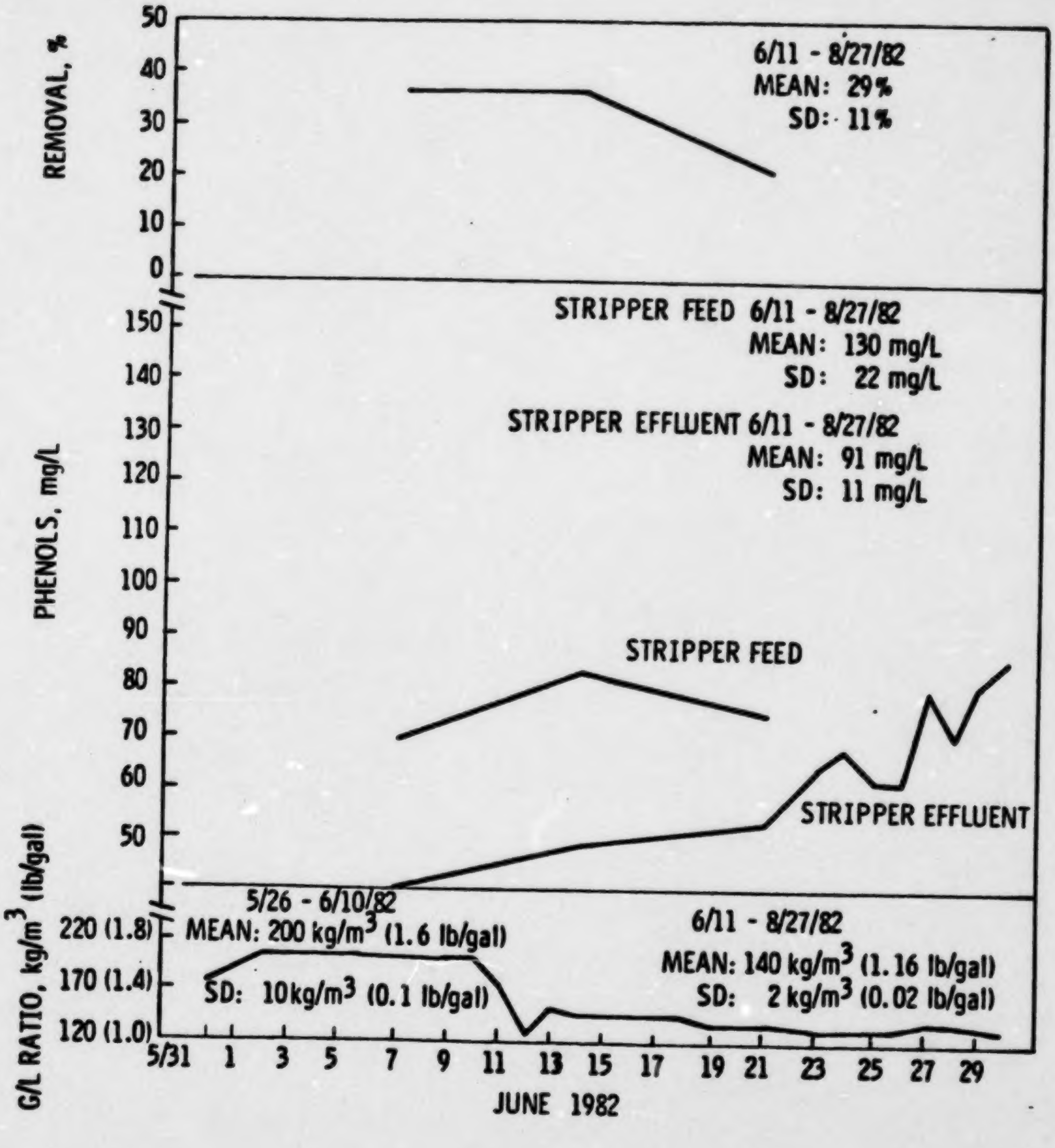

Figure 36. Long-term steam stripper performance - phenols removals between June 1, 1982 and August 26, 1982.

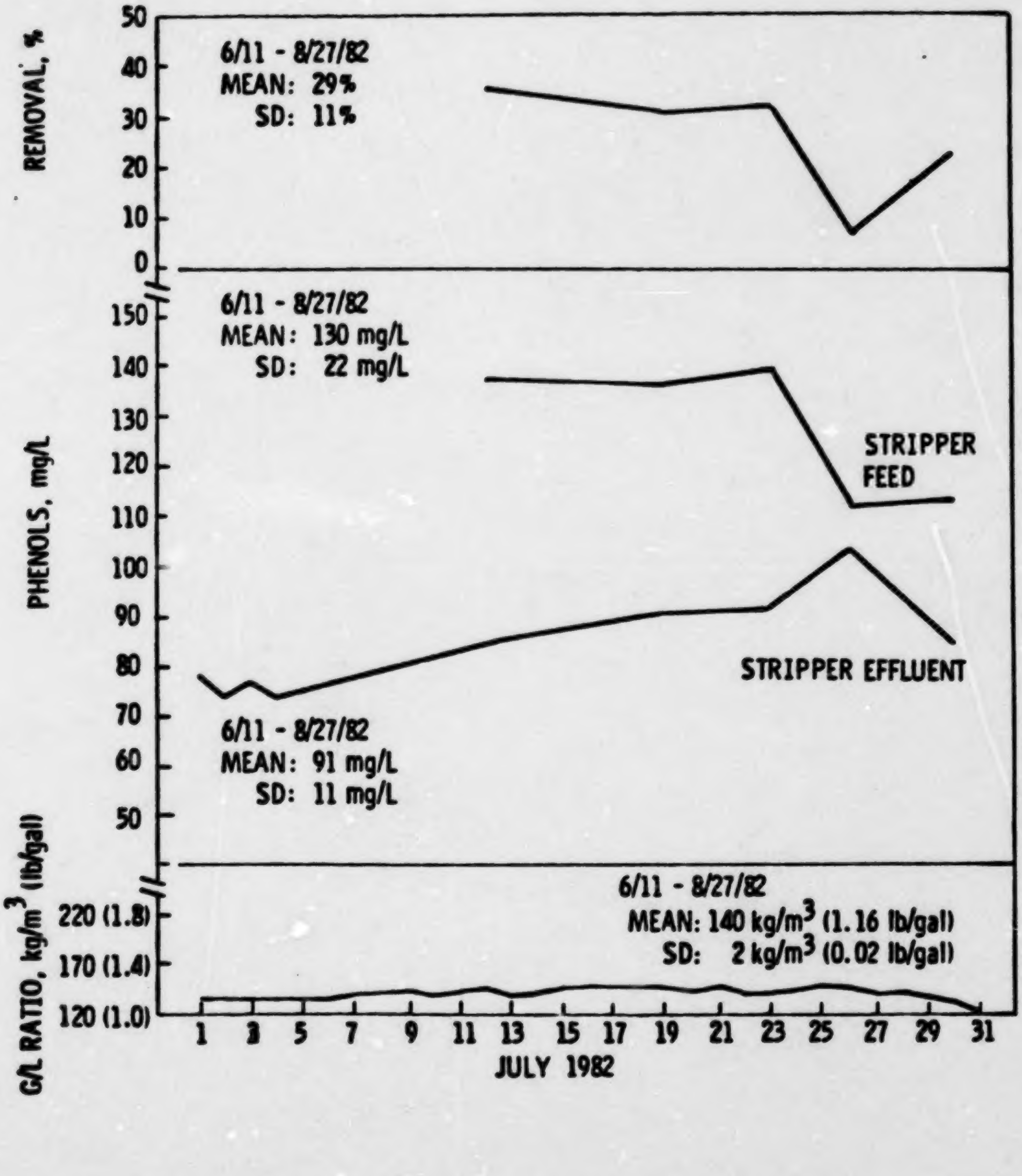

Figure 36 (continued)

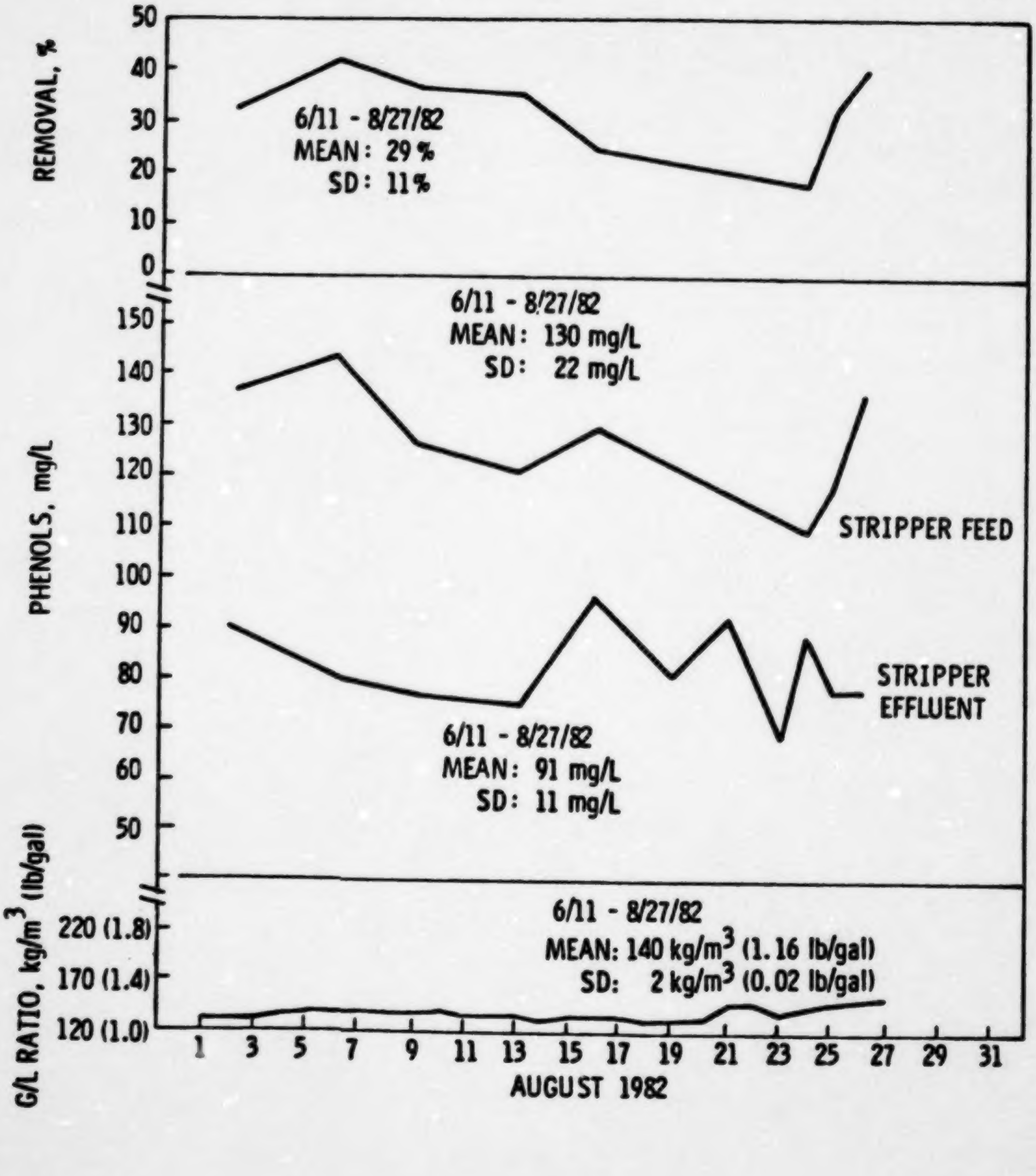

Figure 36 (continued)

Ammonia, alkalinity, TKN, and sulfide removals were excellent (greater than 95%) during the entire period. The range of percent removal was narrow, indicating very good long-range stability of the steam stripper operation and performance.

Over the test period from June 11 to August 26, 1982, COD removals ranged from 36% to 78%, and DOC removals ranged for 34% to 89%. The removal efficiency for both parameters decreased steadily during the period even though G/L ratios remained constant. This could have resulted from the steadily increasing COD and DOC levels in the gas condensate (stripper feed) produced by Retorts 7 and 8 during the test period.

Removal of phenols varied from 7% to 42% and averaged 29%. As indicated in Figure 36, phenols removals did not follow any specific trend over the test period.

Because a continuous supply of cooling water was not available at the Logan Wash test site, the stripper was operated most of the time with the overhead uncondensed and vented to the atmosphere. The difference between a parameter concentration in the stripper feed and the stripper effluent was used to evaluate stripper removals. Feed and bottom rates to and from the stripper were essentially the same (a constant level was maintained in the stripper column, thus, the flow out equalled the flow in) and this percent removal calculation is similar to calculations based on mass alone. However, no calculations based on mass were made. To provide some indication of pollutant distribution between the stripper effluent and stripper overhead, the stripper was operated at a constant liquid feedrate of 158 cm^3/s (2.5 gal/min) with constant steam-to-liquid ratio of 144 kg/m^3 (1.2 lb/gal). For approximately two hours, municipal water was used to condense the stripper overhead and this overhead was collected as a condensate sample. Simultaneous grab samples of the stripper feed, stripper effluent, and stripper overhead were taken and analyzed for ammonia, metals and organics (by GC/MS and DOC fractionation). During this time period, stripper bottoms maintained an average flow rate equal to the column feed rate (158 cm^3/s or 2.5 gal/min) and the overhead rate was approximately 19 cm^3/s (0.3 gal/min). The test results for GC/MS organics, metals, and DOC fractions are summarized in Tables 24 through 26. Table 27 shows ammonia grab sample results and present a material balance for the stripper system.

Phenolic and pyridine compounds (50% and 20%, respectively) constituted 70% of the organics in the stripper feed, while phenolic compounds constituted 73% of the organics in the stripper bottoms. The major constituents of the overhead vapor condensate organics were pyridine compounds (28%) and unidentifiable compounds (58%). The stripper bottoms and the overhead vapor condensate contained some compounds that were not found in the stripper feed. This discrepancy was caused by the different matrixes in which the compounds were present in the feed, bottoms, and overhead vapor condensate.

The stripper feed had a low metal content, and many metals were present at concentrations below the detection limit of the analytical method. The concentrations of metals detected in the three streams sampled varied little from stream to stream and were at very low levels or below the detection limits.

A review of DOC fractions data shows that 63% of the hydrophobic and 69% of the hydrophilic compounds (refer to Table 8 for a list of the compounds) were removed by the steam stripper. As indicated in Table 26, base and neutral fraction removals in both categories were greater than 60%.

TABLE 24. STEAM STRIPPER PERFORMANCE DATA FOR PURGEABLE AND EXTRACTABLE ORGANICS[a]

Organic compound	Concentration, mg/L[b] Feed	Bottoms	Overhead vapor condensate
Base/Neutral Extraction Fraction			
Pyridine compounds and their isomers	100		140
Trichloromethane	3.2	4.9	1.3
Benzene	5.4	4.9	4.8
Cyclohexene	9.3	11	2.5
Methylcyclopentenone	2.6		
Phenolic compounds and their isomers	150	230	
Trimethylcyclohexanone	3.9		
Quinoline and/or isoquinoline	2.9	1.9	11
1H-Indole or benzeneacetonitrile	2.1		2.1
Methyl quinoline or methyl isoquinoline	3.4		11
Unknown	67	10	140
2-Cyclopenten-1-one, 3-methyl		3.1	
Pyrrole compounds		19	
Benzamine		22	
Methyl indole and/or methyl indolizine (isomer)		3.3	
Acid Extraction Fraction			
Trichloromethane	1.9	6.3	5.9
Benzene	4.2	5.4	5.5
Cyclohexane	10	12	13
Carboxylic acid	20		
Phenols	110	73	0.12
Alkene $\geq C_8$	0.81		
Unknown	7.2		150
Furanone, 5-hexyldihydro			0.13
Furanone, 5-ethyldihydro-5-methyl			0.35
Possible chlorine-containing unknown			0.3
Silicon-containing unknown			0.18
Sulfur			7.3
Unknown phthalate			2.2

[a] One grab sample taken on June 16, 1982.

[b] Blanks indicate compound below detection limits.

TABLE 25. STEAM STRIPPER PERFORMANCE DATA FOR METALS[a]

	Concentration, mg/L		
Metal	Feed	Bottoms	Overhead vapor condensate
Ag	<0.19	<0.19	<0.19
Al	0.20	0.15	0.25
As	<0.01	<0.01	0.01
B	0.36	0.42	0.10
Ba	<0.01	<0.01	0.01
Be	<0.01	<0.01	<0.01
Ca	1.91	2.19	2.67
Cd	<0.01	<0.01	<0.01
Co	<0.04	<0.04	<0.04
Cr	<0.02	<0.02	0.02
Cu	<0.03	<0.03	0.07
Fe	0.16	0.16	0.75
Hg	<0.01	<0.01	0.02
K	<2.6	<2.6	<2.6
Mg	0.18	0.23	0.20
Mn	<0.01	0.02	<0.01
Mo	<0.05	<0.05	<0.05
Na	<10	<10	<10
Ni	<0.08	<0.08	0.14
Pb	<0.1	<0.1	<0.1
Sb	<0.38	<0.38	<0.38
Se	<0.01	<0.01	<0.01
Sn	<0.5	<0.5	<0.5
Sr	<0.01	<0.01	0.01
Ti	<0.02	<0.02	<0.02
V	<0.03	<0.03	<0.03
Zn	0.19	0.03	0.08

[a] Grab sample taken on June 16, 1983.

Ammonia concentration in the condensed overhead was approximately 77,000 ppm (see Table 27). Flow rates in lb/hr are based on gal/min rates and measured stream temperatures. The material balance closure for ammonia is excellent (103%).

Every 7 to 10 days the liquid throughput to the stripper column decreased from 190 cm^3/s (3.0 gal/min) to 127-158 cm^3/s (2.0-2.5 gal/min) as a result of partial clogging of the overhead vapor

TABLE 26. STEAM STRIPPER PERFORMANCE DATA FOR DOC FRACTIONS[a]

Parameter/fraction	Concentration, mg/L			Percent[b] removal	Fraction distribution, %		
	Feed	Bottoms	Overhead vapor condensate		Feed	Bottoms	Overhead vapor condensate
Total DOC	480	170	1,800	65			
Hydrophobic fraction	220	82	610	63	45	49	51
Base	98	12	240	88	65	12	17
Acid	48	46	180	4	73	73	69
Neutral	74	24	190	68	27	33	16
Hydrophilic fraction	270	85	1,200	69	55	51	49
Base	52	20	150	62	35	88	83
Acid	18	17	80	6	27	27	31
Neutral	200	48	970	76	73	67	84

[a] Grab sample sample taken on June 16, 1982.

[b] Based on feed and bottoms concentration.

TABLE 27. STEAM STRIPPER PERFORMANCE DATA FOR AMMONIA GRAB SAMPLES (June 16, 1982)

Stripper sample location	Flow rate, lb/hr	NH_3-N concentration, mg/L	NH_3-N mass rate, lb/hr	Sum of in or out mass rates, lb/hr	Material balance closure, %[a]
Feed	1,219	9,660	12.08	12.08	103
Steam	180	~0[b]	~0[b]		
Bottoms	1,248	98	0.12	11.70	
Overhead	151	77,140	11.58		

[a] IN ÷ OUT rates.

[b] Not analyzed, assumed equal to zero.

lines with condensed ammonium carbonate. This increased the pressure in the stripper column and eventually resulted in column flooding. Blowing steam through the packing for several hours did not completely eliminate the clogging problem, but it did raise the liquid throughput to 190 cm^3/s (3.0 gal/min) again. Despite this problem, the stripper performed very well, required minimal attention, and supplied a steady feed for biological treatment.

The stripper packing was inspected at the end of the study and a black deposit was observed. The deposit was analyzed and found to contain 66% nickel and 25% copper.

4.3.4 Conventional Activated Sludge Treatment

The feasibility of removing organics from steam-stripped gas condensate by the conventional activated sludge process was evaluated from May 25 to August 10, 1982. This subsection describes the treatment and the results obtained.

4.3.4.1 Bioreactor Startup and Acclimation

Operation of a continuous-flow, completely mixed activated sludge reactor system was begun on May 25, 1982, using the following startup operating conditions and the aeration basin and clarifier described in Section 3.5:

Reactor hydraulic loading rate: 41.7 cm^3/s
Reactor hydraulic retention time: 24 hours
Mean cell residence time (sludge age): 30 days
Clarifier overflow rate: 9.3×10^{-6} $m^3/m^2 \cdot s$
Operating tank liquid volume: 3.6 m^3
Operation: Complete mix

Raw gas condensate water had an average ammonia concentration of approximately 8,600 mg/L. Since this value is considerably higher than the concentration that begins to inhibit the activated sludge process (480 mg/L) [5], the raw gas condensate required pretreatment for ammonia removal; this was done using the steam stripper. Section 4.3.3 presents performance data on the stripper and describes the quality of the stripper bottoms generated for use as feed to the activated sludge reactor.

Nutrients were added to the activated sludge reactor to sustain microorganism growth in the biological system. Nutrient addition requirements were determined from bench-scale activated sludge treatment of Occidental Retort No. 6 gas condensate and were based upon approximate values of cell composition and assumed maximum values of sludge wastage rate. Phosphoric acid (H_3PO_4), magnesium sulfate ($MgSO_4 \cdot 7H_2O$), and ferric chloride ($FeCl_3 \cdot 6H_2O$) were found to be deficient and were added to the steam-stripped wastewater in quantities sufficient to maintain phosphorus, magnesium, and iron concentrations of 7.5, 1.25, and 0.50 mg/L, respectively.

The reactor was seeded with sludge obtained from the secondary clarifier of an activated sludge treatment plant treating coke plant wastewater at a steel mill. This sludge was added to each of the 4 sections in a sufficient amount to result in 17,000 mg/L of mixed liquor volatile suspended solids (MLVSS) in the aeration basin. The stripped gas condensate flow was then gradually adjusted to 41.7 cm^3/s within the following 24 hours of reactor operation.

A number of operational problems were encountered during the acclimation period. They are summarized below (additional details are provided in Appendix A):

- The high mixed liquor suspended solids (MLSS) concentration (28,000 mg/L) caused rapid accumulation of thick sludge at the inlet to the secondary clarifier and resulted in frequent plugging of the aeration basin overflow line. This problem, prevalent over the first two days, was resolved by periodically unclogging the aeration basin overflow line, and by solids loss from sludge overflow from the secondary clarifier, which decreased the mixed liquor solids level in the bioreactor.

- The overflow from the aeration basin was saturated with air. As the liquid flowed into the overflow pipe from the basin the air separated from the liquid, causing an air lock (or air pockets) in the overflow pipe and severely reducing the flow through the pipe and hose connecting the aeration basin with the secondary clarifier; this caused the aeration basin to overflow. This problem was corrected by installing an aeration basin overflow chamber or holding tank, which allowed the air to separate from the water prior to the liquid entry into the hose connecting line and the secondary clarifier.

- The aeration basin overflow was characterized by poor sludge settling characteristics. Hence, the sludge did not settle in the secondary clarifier and was lost in the clarifier overflow. Alum was added to the aeration basin overflow to improve sludge settleability. Also, during the poor sludge settling period, fresh seed sludge was periodically added to the aeration basin to prevent rapid depletion of biological solids.

- Uniform operation of the aeration basin could not be maintained. The aeration basin comprised four sections of unequal volumes, as described in Section 3.5, and was to be operated as a completely mixed homogeneous reactor. To achieve uniform operation of each section, it was necessary that each section be fed with stripped effluent flow in proportion to its volume. This could not be done because the section flow distribution tubes built sludge deposits as the mixed liquor splashed against them; this, in turn, made the flow distribution unpredictable. Similarly, sludge returning from the clarifier had to be distributed in proportion to the volume of each section; this distribution could not successfully be done owing to system design limitations. Cutting holes into the walls between the sections to facilitate intersectional mixing and thus equalize the aeration basin operating conditions improved but did not correct the situation. Thus, the aeration basin operated as four distinct reactors rather than as one homogeneous reactor until three of the sections were removed from use as described below.

- From May 25 to June 10, the steam stripper was operated to produce an effluent with an ammonia concentration of 20-25 mg/L. As noted earlier, this resulted in a COD concentration that was believed to be too low based on decreasing MLVSS concentrations and dissolved oxygen uptake rates to sustain a viable biological treatment. Although raising the ammonia level to 80-120 mg/L increased the COD levels, a further increase in the organic loading of the system was believed to be necessary based on the above criteria and conversations with several biological treatment experts. This was done by decreasing the hydraulic retention time, from 24 hours to 16 hours. The retention time was reduced by taking out of service the three smallest sections in the aeration basin and decreasing the inlet flow to this basin.

- On June 5 (the tenth day of reactor operation) stripped retort water rather than stripped gas condensate was inadvertently fed to the aeration basin (operator error). This upset the system and interrupted its acclimation. Several days were needed to restore equilibrium.

- During July 4 to July 8, owing to development of a leak in the aeration basin overflow line, most of the biological solids from aeration basin Section 4 flowed into Sections 2 and 3 instead of the secondary clarifier. Sections 2 and 3 were out of operation during this period. This caused a large drop in MLSS and MLVSS levels in Section 4, and necessitated transfer of large quantities of sludge from Sections 2 and 3, as shown in Table 28.

TABLE 28. SEEDING SCHEDULE FOR BIOSYSTEM

Date 1982	Quantity of sludge added, m^3 (gallons)
6/21	0.380 (100)
6/29	0.060 (15)
6/30	0.020 (5)
7/1	0.020 (5)
7/2	0.040 (10)
7/3	0.040 (10)
7/4	0.040 (10)
7/7	0.060 (20)
7/8	0.095 (25)
7/9	0.360 (95)
7/10	0.400 (105)
7/11	0.285 (75)
7/12	0.130 (35)

- Foaming problems were occasionally encountered in the aeration basin, and were eliminated by adjusting the air flow rate and/or agitator speed of the aeration basin.

Because of some of these problems and the changes needed to deal with them, the biological reactor performance was not evaluated from May 25 to June 15. From June 16 to July 12, one section of the aeration basin was operated at a hydraulic detention time of 16 hours. A sludge settling problem was still present, and a significant quantity of biological solids was being lost in the secondary clarifier overflow. This prevented development of a viable population of organisms in the bioreactor. To combat this problem, no sludge other than the overflow sludge was discarded, and fresh seed sludge was periodically added to the aeration basin, as noted in Table 28. Also, alum (at 120-150 mg/L) was added continuously to the aeration basin effluent to help sludge settling. Although these measures resulted in considerable improvement, the TSS and VSS levels in the clarifier overflow continued to be high, as shown in Figure 37. Also, the MLSS and MLVSS concentrations varied significantly, as shown in Figure 38, owing to sludge addition and loss of biological solids from the clarifier overflow.

Plots of dissolved oxygen (DO) concentration and uptake rate during the acclimation period are presented in Figure 39. The DO concentration was maintained well above 2 mg/L so that growth would not be oxygen-limited. The DO uptake rate varied from 1.4 to 7 mg/m^3/s and was generally erratic due to the addition of new seed sludge.

Soluble COD was used as an indication of the ability of the system to remove organics. Influent and effluent soluble COD values, along with percent removal, are presented in Figure 40. After June 22, removal rates were generally greater than 50%, except for July 4 and 5 when the biological solids level in the aeration basin was low. These removals remained relatively unchanged despite the fact that influent and effluent COD concentrations were gradually increasing over the acclimation period.

Influent and effluent also were analyzed for DOC and soluble BOD$_5$. The DOC and BOD$_5$ data, along with removal rates, are plotted in Figures 41 and 42, respectively. DOC influent and effluent concentrations increased with time, and removal rates were generally greater than 50%, except for July 4 and 5 when MLVSS level was low in the aeration basin. BOD$_5$ concentrations increased with

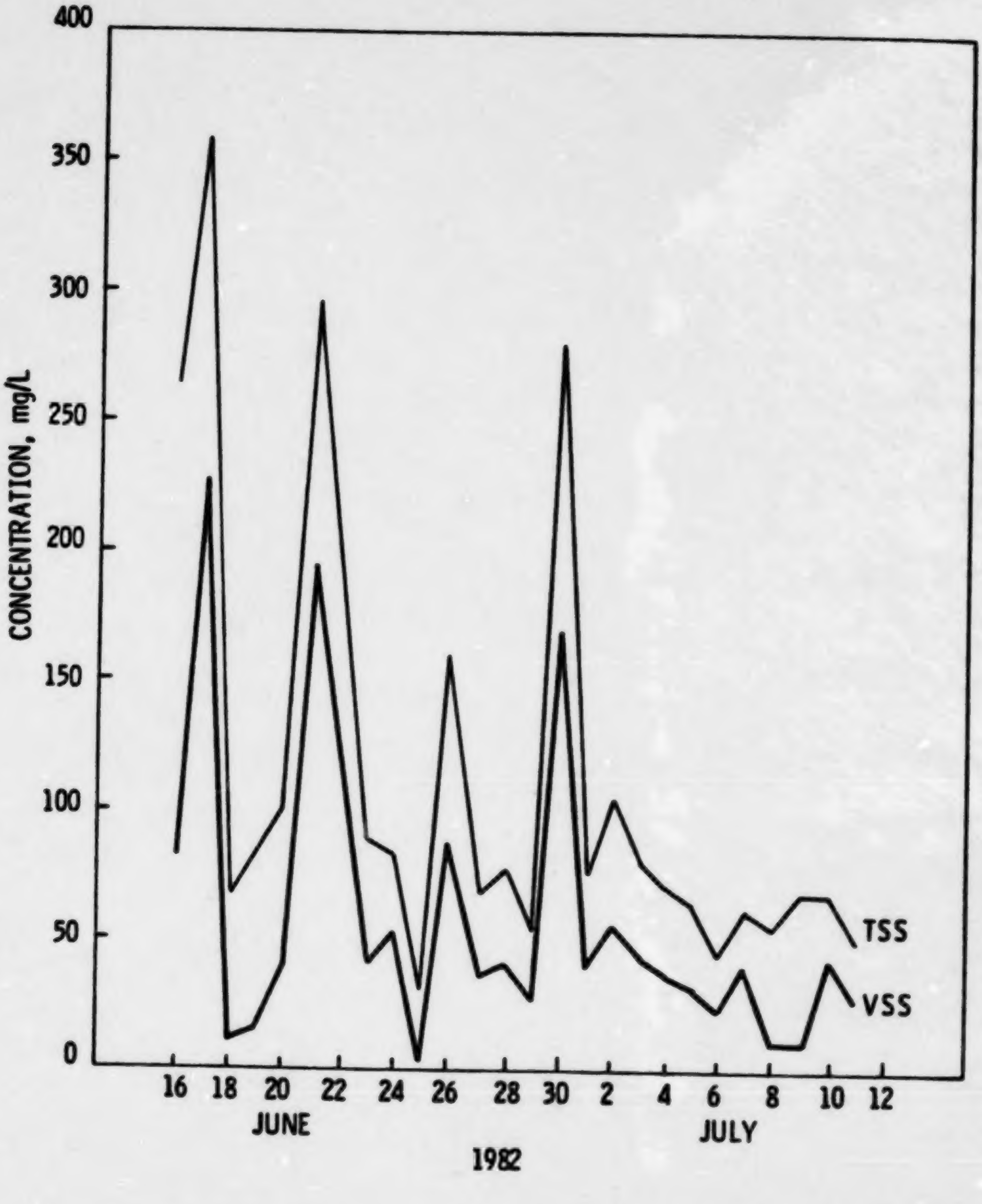

Figure 37. TSS and VSS concentration in secondary clarifier effluent during biological reactor acclimation period.

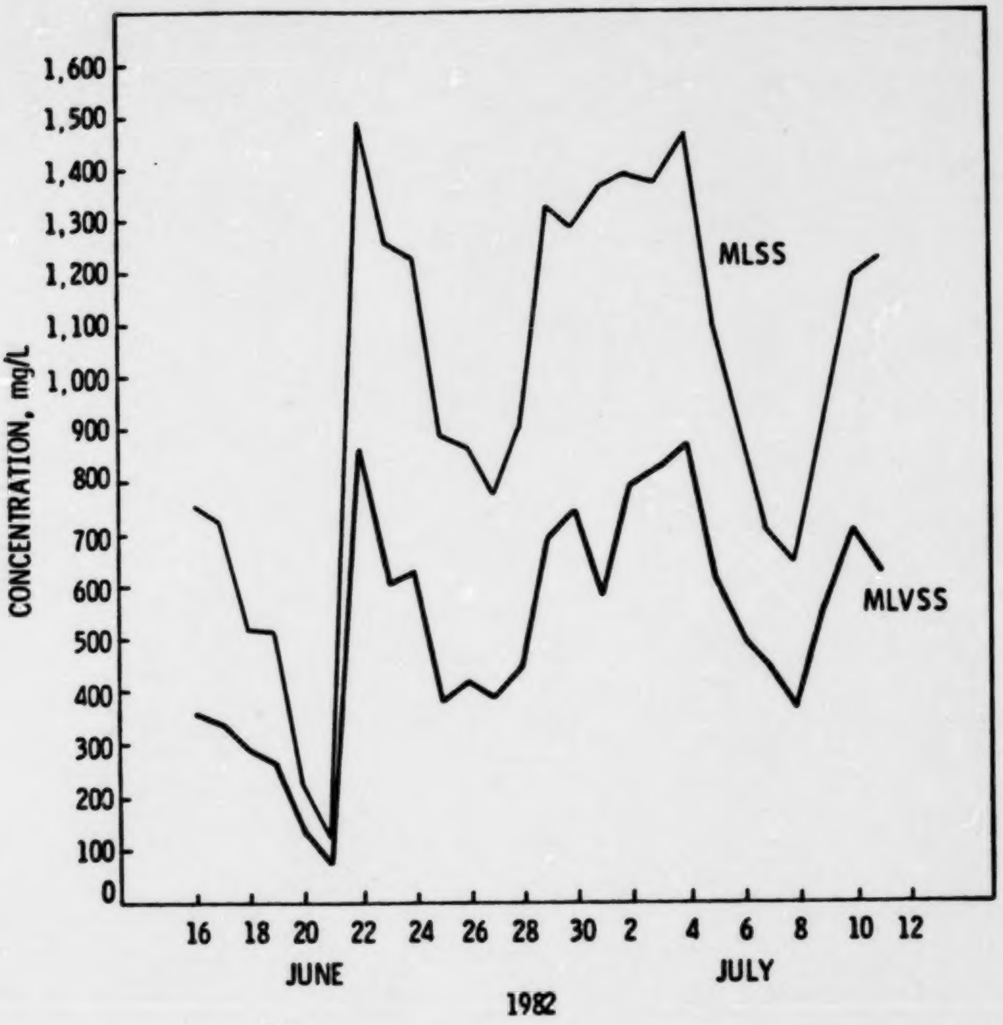

Figure 38. MLSS and MLVSS concentrations in biological reactor during acclimation period.[a]

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[a] Seed sludge was added several times during acclimation phase.

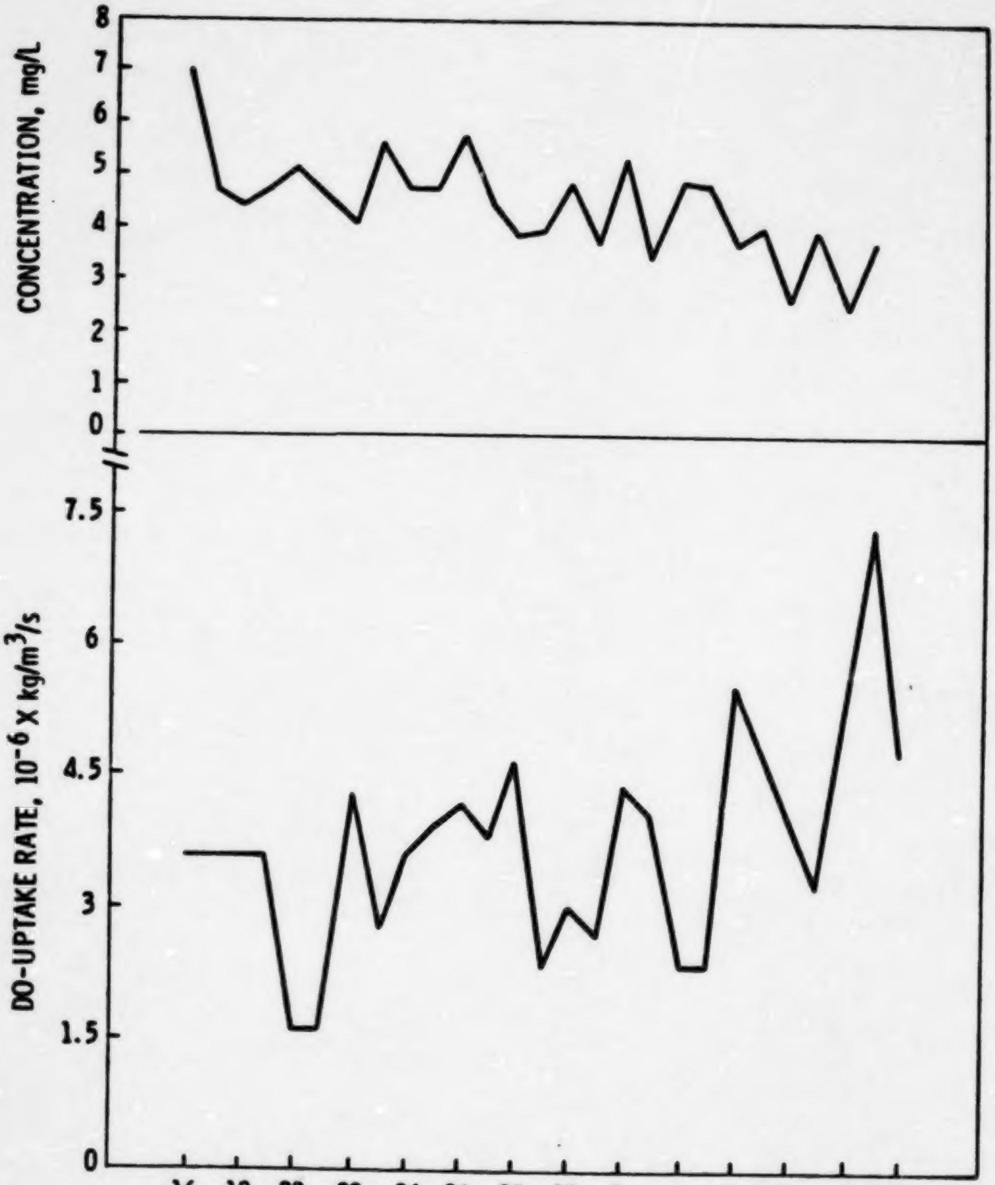

Figure 39. Dissolved oxygen (DO) concentration and DO-uptake rate in biological reactor during acclimation period.

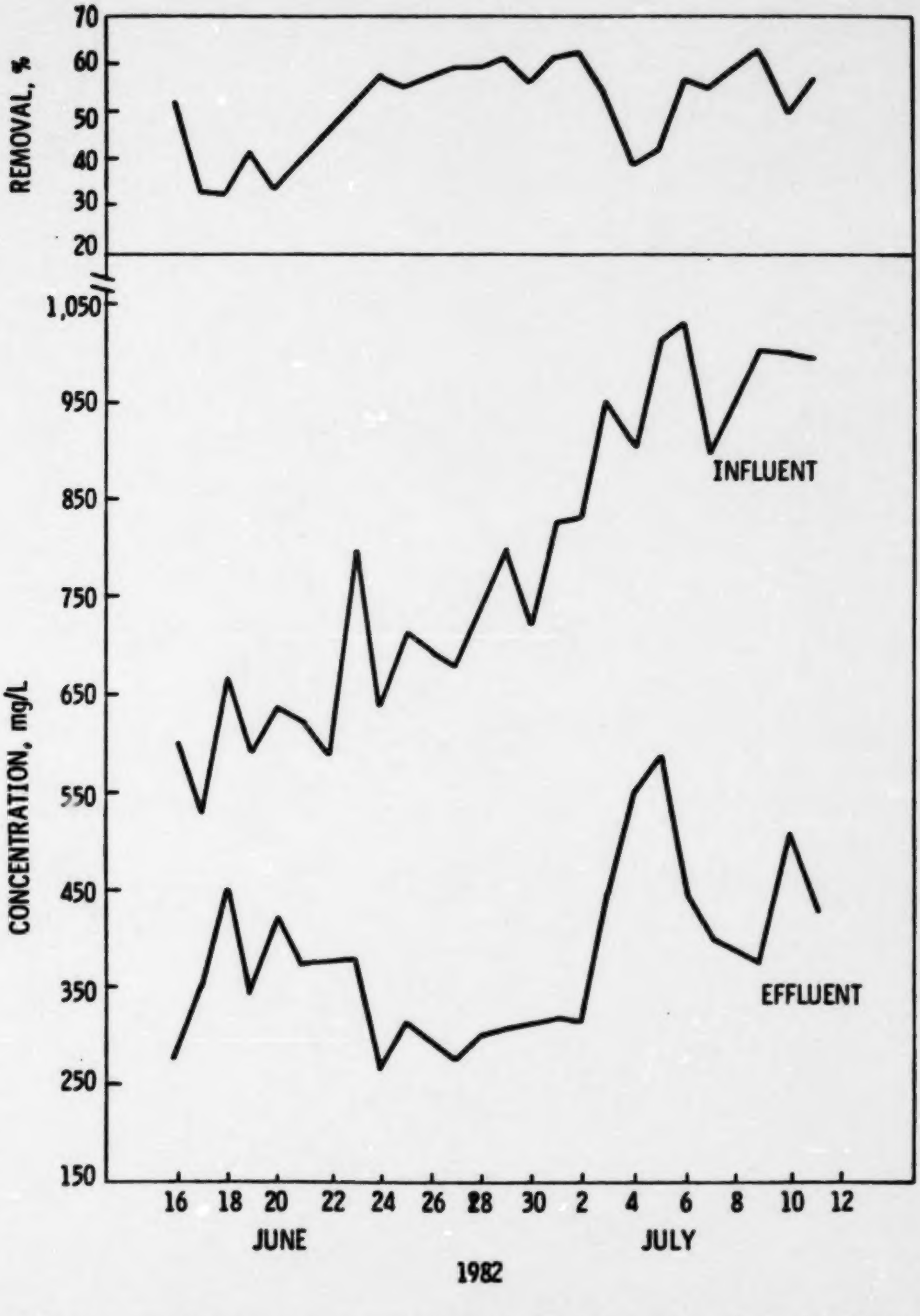

Figure 40. Soluble COD concentration and removal in biological reactor during acclimation period.

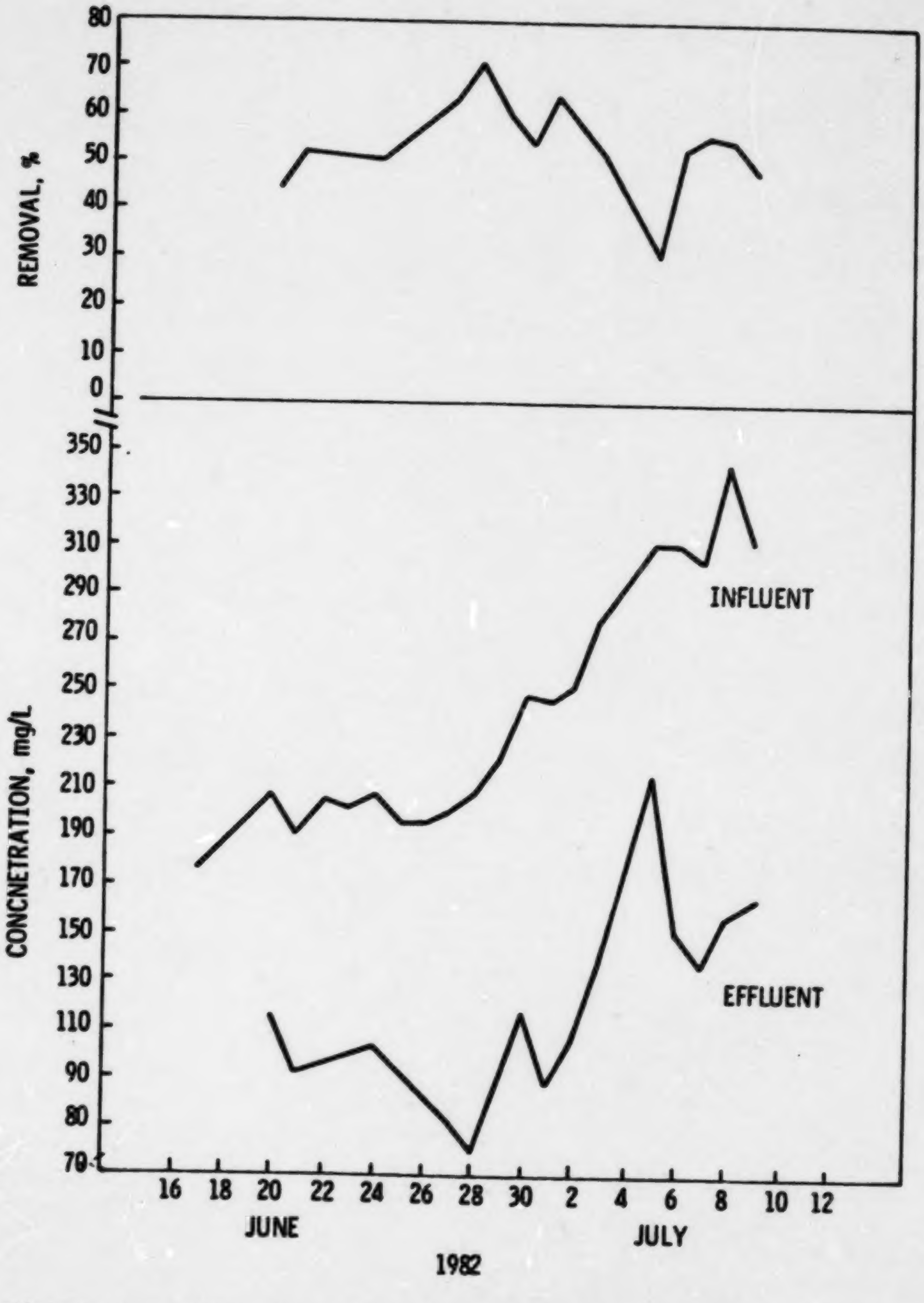

Figure 41. DOC concentration and removal in biological reactor during acclimation period.

time, and the average removal rate was approximately 80% during the acclimation period. The BOD_5 removal rate varied with MLVSS level in the aeration basin.

Influent and effluent concentrations for phenols, along with removal rates, are plotted in Figure 43. Over 95% removals were obtained except when the MLVSS concentration in the aeration basin was low.

Bioreactor influent and effluent pH values are plotted in Figure 44. The effluent pH was generally one unit lower than the influent pH and in the 7.0-8.0 range. Influent pH adjustment was not required to maintain the bioreactor pH in the desired range of 7.0-8.0.

4.3.4.2 Bioreactor Steady-State Performance

After the acclimation period (May 25 - June 15), the dissolved oxygen uptake remained greater than 6×10^{-6} kg/m^3/s (22 mg/L/hr) and COD and BOD_5 removals remained rather constant. This did not necessarily indicate that steady-state was achieved but rather than consistently high removals of organics could be obtained and that a bilogical system could be sustained. Bioreactor performance monitoring data collected after the acclimation period are summarized in Tables 29 through 31 and in Figures 45 through 50. The data summarize bioreactor performance monitoring records. Bioreactor operating conditions and performance are discussed below, for each parameter.

Retention times - The hydraulic retention time (HRT) and the sludge age or solids retention time (SRT) are the two parameters that were used to control the activated sludge process. For the data collection period, the average HRT was 16 hours with minimal variation [±1 S.D. (standard deviation) where S.D. = <0.1h] in HRT

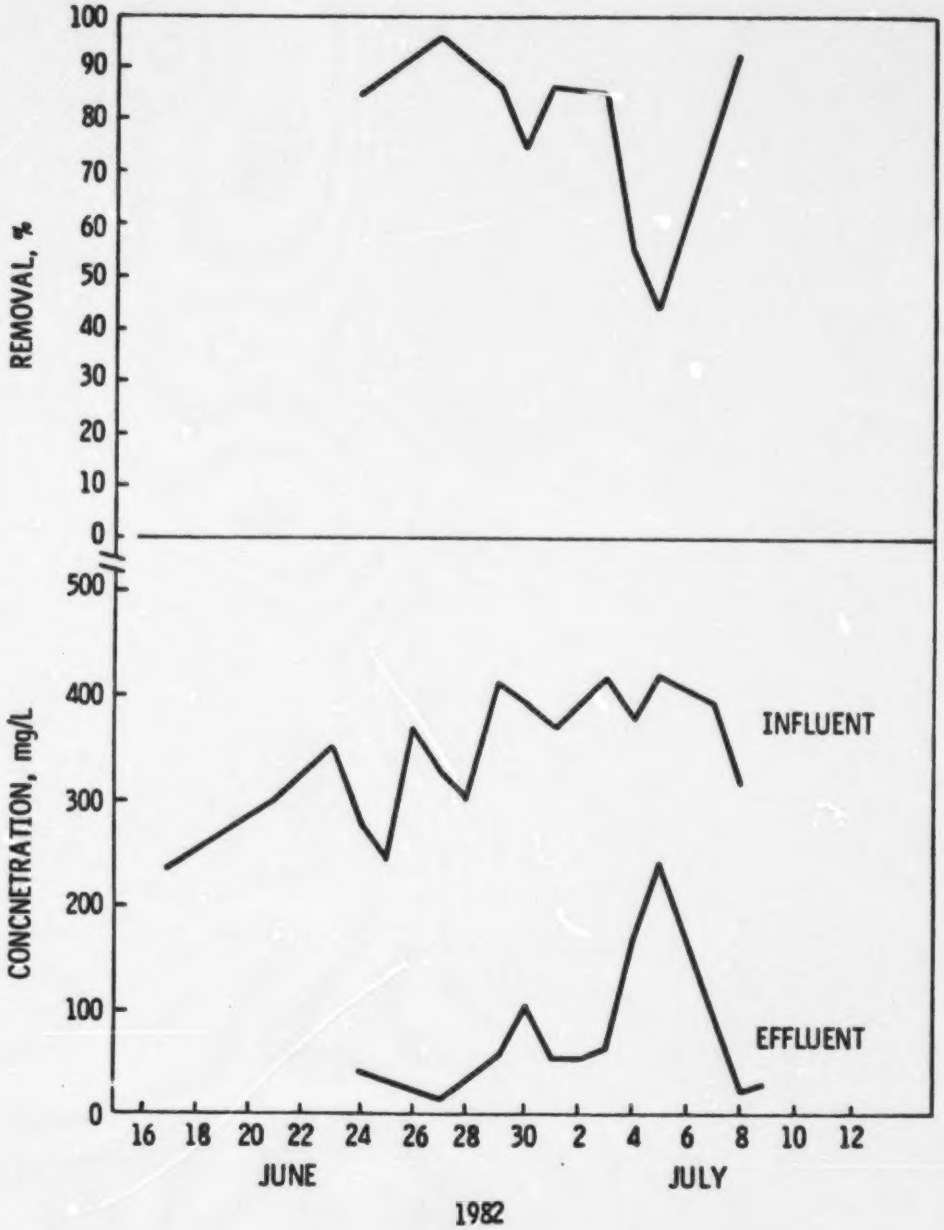

Figure 42. Soluble BOD5 concentration and removal in biological reactor during acclimation period.

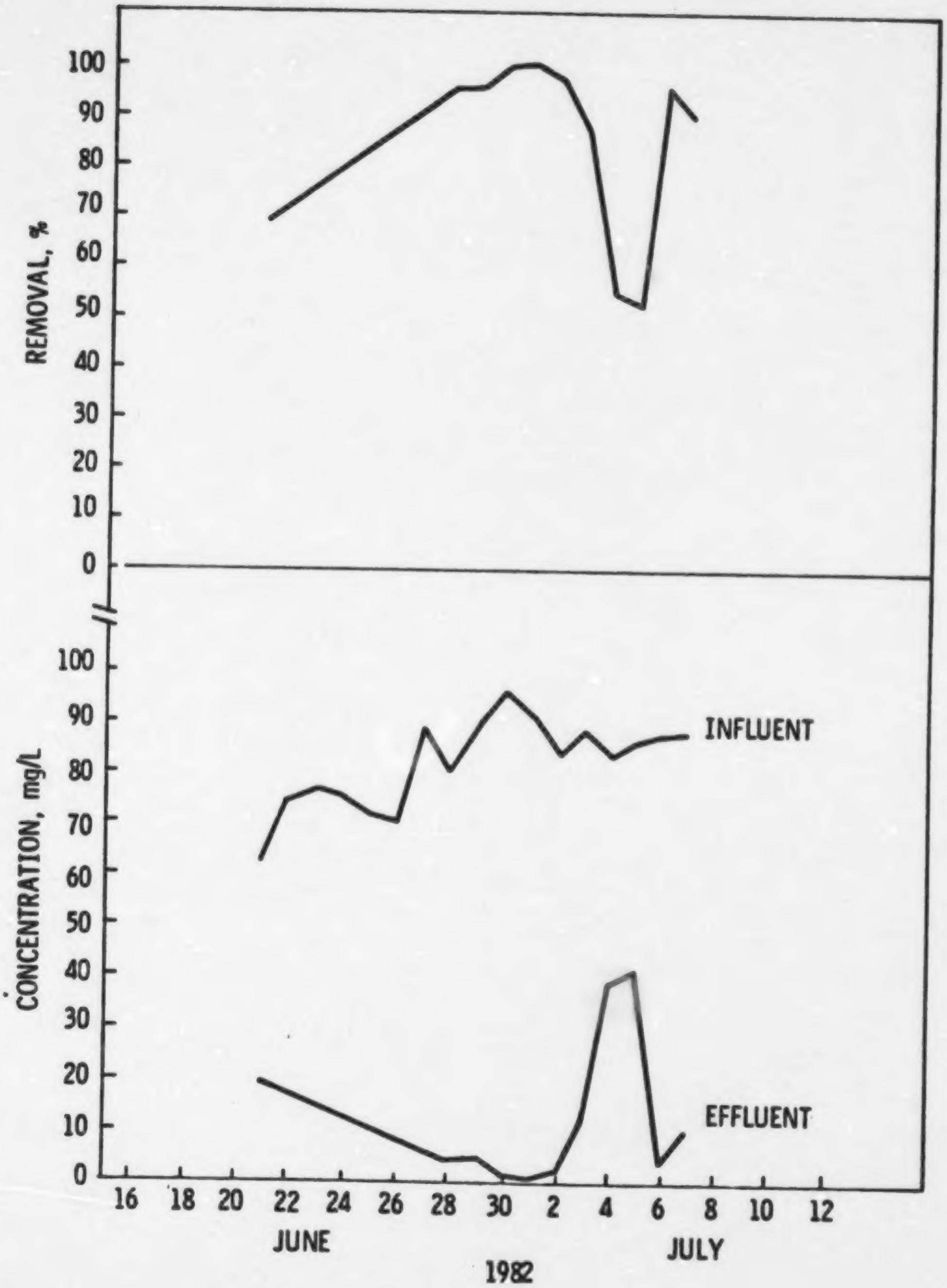

Figure 43. Phenols concentration and removal in biological reactor during acclimation period.

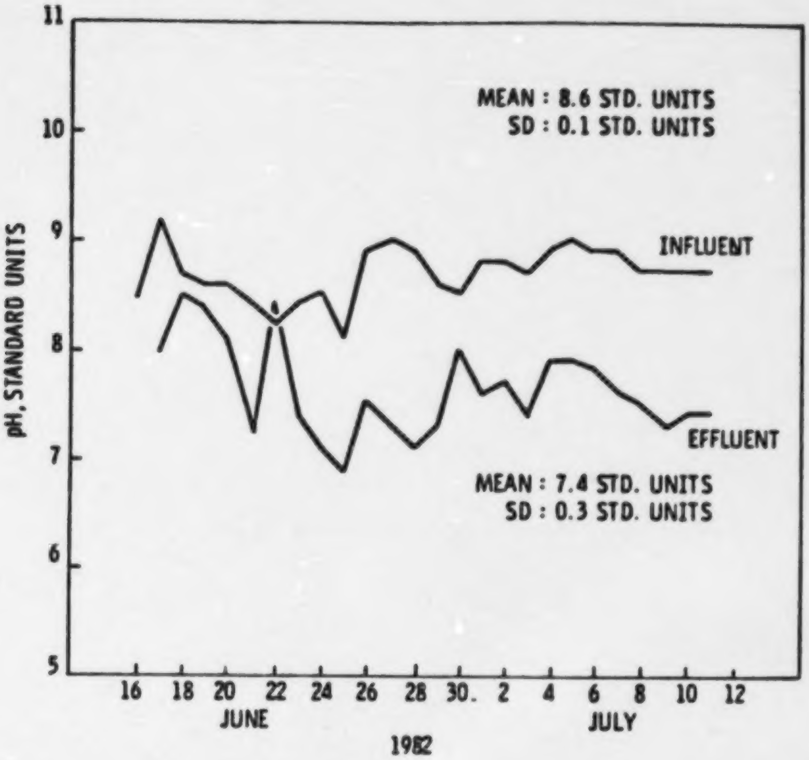

Figure 44. pH in biological reactor during acclimation period.

as indicated by the flowrate data in Appendix C. The SRT is defined as the total quantity of active microbial mass in the aeration basin divided by the total quantity withdrawn daily. The total quantity withdrawn daily includes the microbial mass lost in the secondary clarifier effluent as well as that purposely removed by disposal of settled sludge from the secondary clarifier. The total volatile suspended solids indicative of the active microbial mass concentration are used to compute the SRT. The average SRT was 32 days for the period July 12 to July 30. High SRT's (>20 days) are typical of extended aeration processes. The system was designed to operate at an SRT of 30 days (refer to Section 4.3.4.1), and it performed very near this desired value. Although the system operated for approximately 1/2 an SRT (July 12 to July 30) and steady-state was not achieved, data was collected

TABLE 29. BIOREACTOR DATA SUMMARY[a,b] FOR CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS

	Influent			Effluent			Percent removal[c]		
	Number of analyses performed	Concentration, mg/L		Number of analyses performed	Concentration, mg/L		Number of pairs analyzed	Percent	
Parameter		Range	Average		Range	Average		Range	Average
Soluble COD	26	1,100-1,750	1,380	42	400-740	584	26	54-63	57
Soluble BOD_5	5	370-580	510	9	9-105	63	5	84-98	91
DOC	6	324-470	416	14	123-272	192	6	38-60	52
Phenols	6	94-114	101	14	3.0-11.5	6.0	4	93-97	95
NH_3-N	20	62-151	96	6	68-92	80	4	0-23	8.3
NO_3-N	3	0.6-1.2	0.9	3	0.5-1.4	0.8	2	23-64	44
pH	98	8.4-8.9[d]	8.6[d]	98	7.0-8.7[d]	7.4[d]	NA	NA	

NA - not applicable.

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[a] Soluble BOD_5 and DOC data pertain to composite samples; phenols and pH data pertain to grab samples; soluble COD, NH_3-N, and NO_3-N data pertain to both grab and composite samples.

[b] Steam stripper operated according to Table 23; (i.e., $G = 2.5 \times 10^{-2}$ kg/hr, $L = 183$ cm^3/s, $G/L = 150$ kg/m^3, Feed Temp. = 81°C).

[c] Numbers in parentheses indicate increase.

[d] Standard pH units.

Parameter	Number of analyses performed	Mixed liquor characterization	
		Range	Average
TSS, mg/L	25	2,150-3,600	2,810
VSS, mg/L	25	1,370-2,300	1,780
DO, mg/L	83	0.5-4.5	2.3
DO uptake rate, 10^{-6} $kg/m^3/s$	25	2.5-14.7	7.5

TABLE 30. BIOREACTOR DATA[a] FOR PURGEABLE AND EXTRACTABLE ORGANICS

Parameter	Concentration, mg/L	
	Influent	Effluent
Base/Neutral Extraction Fraction		
Trichloromethane	4.9	4.1
Benzene	4.9	5.5
Cyclohexene	11	12
Quinoline and/or isoquinoline	1.9	-[b]
Unknown	9.8	7.4
2-Cyclopenten-1-one, 3-methyl	3.1	2.8
Acid Extraction Fraction		
Trichloromethane	6.3	4.5
Benzene	5.4	5.3
Cyclohexene	12	17
Phenols	73.5	2.5

[a] Data are for one composite sample for both the influent and effluent taken on August 4, 1982.

[b] Blank indicates compound not detected.

during this time period to show the levels of organics removal that can be obtained. The SRT for the period July 31 to August 10 is not included for the reason discussed in the following subsection.

MLSS and MLVSS - MLSS and MLVSS levels varied significantly, as shown in Table 29 and Figure 45. This was partly due to inadequate mixing in the aeration basin and partly to the loss of solids in the secondary clarifier effluent, requiring that no sludge be disposed of from the system [except for the 0.02 m^3 (5 gallons) disposed of on July 23]. On July 30, 1,800 grams of powdered activated carbon was added by mistake to the aeration basin. This caused the MLSS and MLVSS levels to increase on August 1. Although data was collected from August 1 to 10, it is not presented in this report as inconsistent levels of organic removals, MLVSS concentrations, and DO uptake rates indicate

TABLE 31. BIOREACTOR DATA FOR METALS[a]

Metal	Concentration, mg/L Influent	Concentration, mg/L Effluent
Ag	<0.19	<0.19
Al	0.15	4.5
As	<0.01	<0.01
B	0.42	0.42
Ba	<0.01	<0.01
Be	<0.01	<0.01
Ca	2.2	6.0
Cd	<0.01	<0.01
Co	<0.04	<0.04
Cr	<0.02	<0.02
Cu	<0.03	0.03
Fe	0.16	0.28
Hg	<0.01	<0.01
K	<2.6	<2.6
Mg	0.23	2.32
Mn	0.02	<0.02
Mo	<0.05	<0.05
Na	<10	11.8
Ni	<0.08	<0.08
Pb	<0.1	<0.1
Sb	<0.38	<0.38
Se	<0.01	<0.01
Sn	<0.5	<0.5
Sr	<0.01	0.02
Ti	<0.02	<0.02
V	<0.03	<0.03
Zn	0.03	0.23

[a] Data are for one composite sample for both the influent and effluent taken on August 4, 1983.

bioreactor upset conditions. The ratio of MLVSS to MLSS averaged about 0.63 for the July 12-30 time period, which is within the range of 0.5 to 1.0 for typical activated sludge systems.

Chemical Oxygen Demand - Soluble COD was the key parameter used to monitor removal of organics in the bioreactor. Influent and effluent COD values along with the corresponding percent removals are presented in Figure 46. The influent COD level varied from

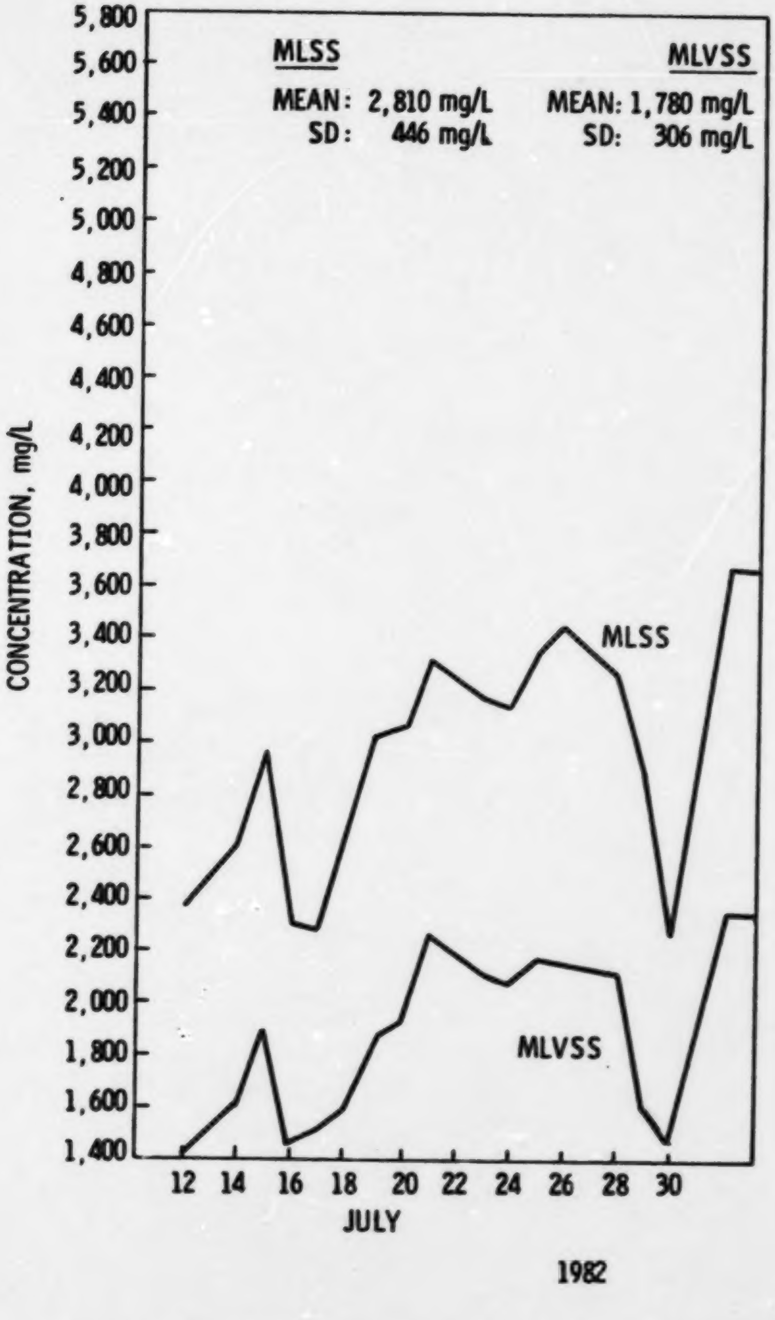

Figure 45. MLSS and MLVSS concentration in biological reactor during July.

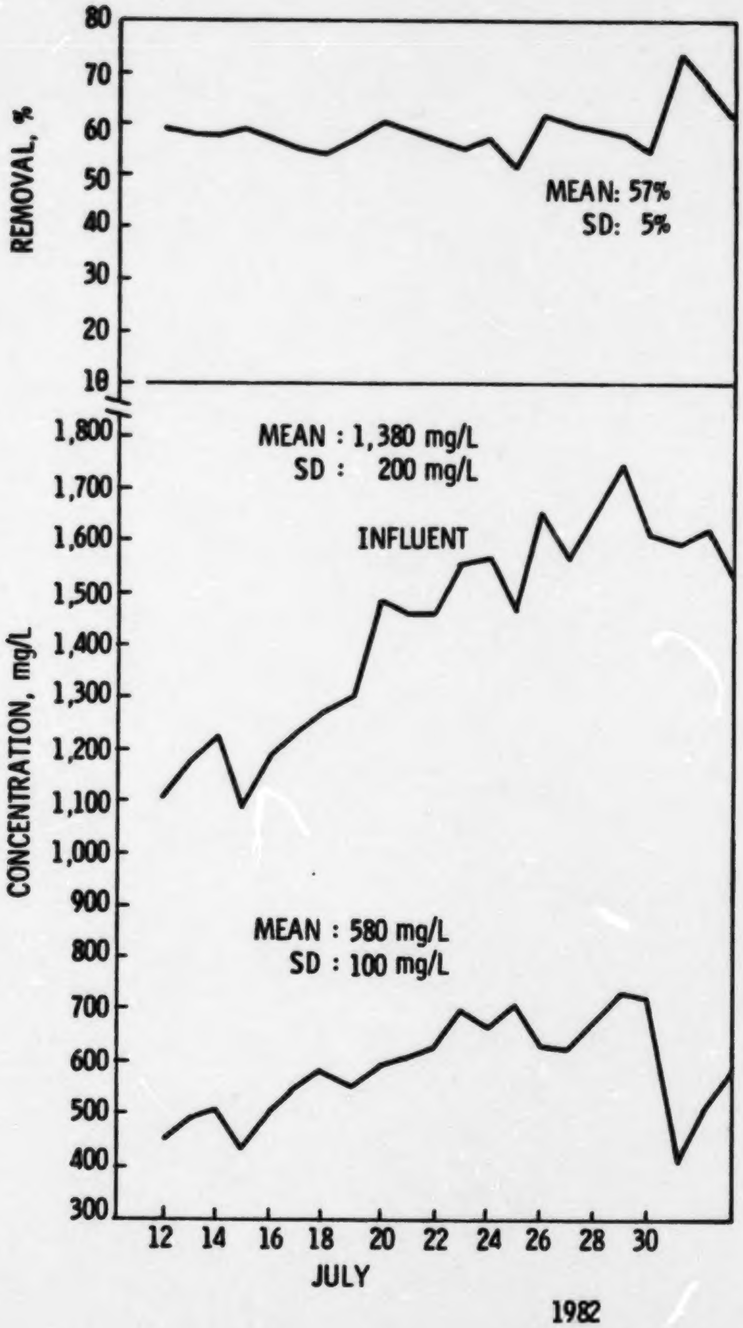

Figure 46. Soluble COD concentration and removal in biological reactor during July.

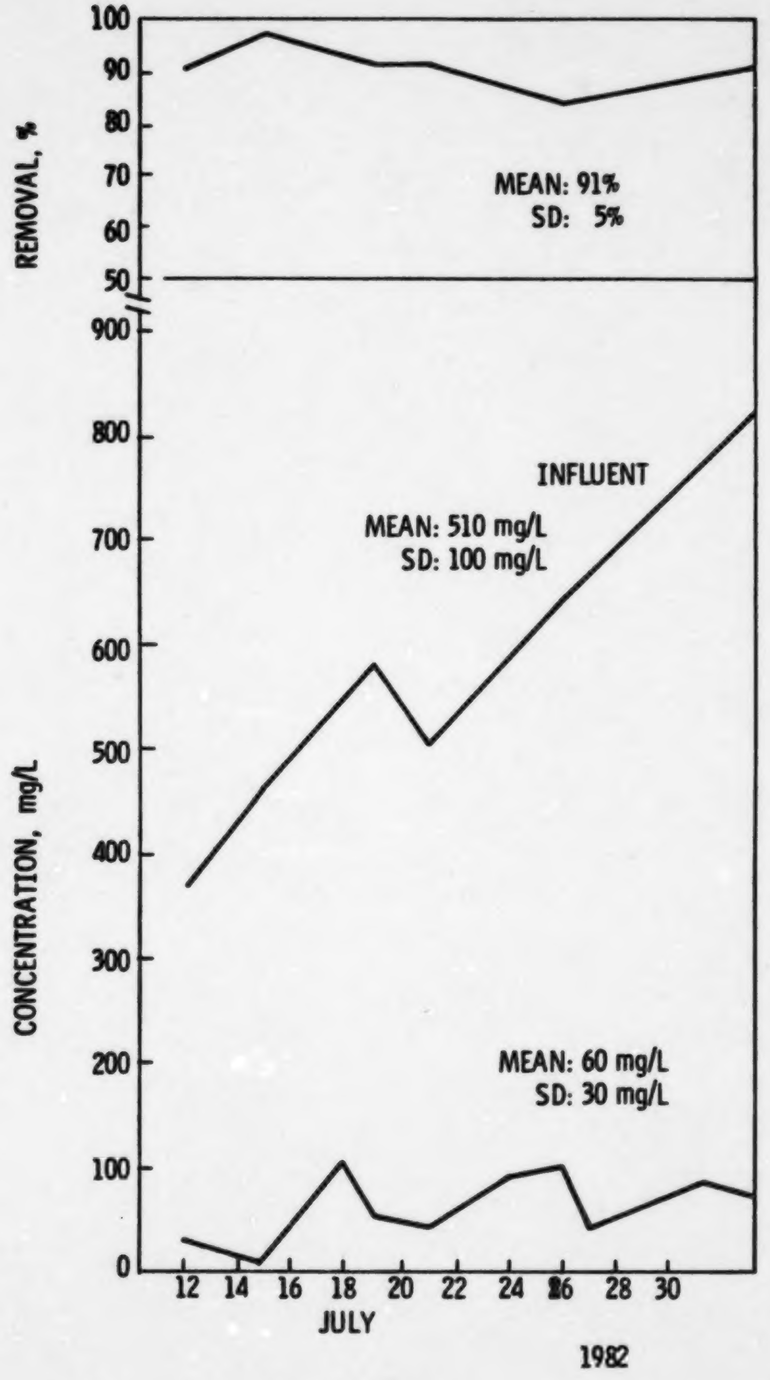

Figure 47. Soluble BOD$_5$ concentration and removal in biological reactor during July.

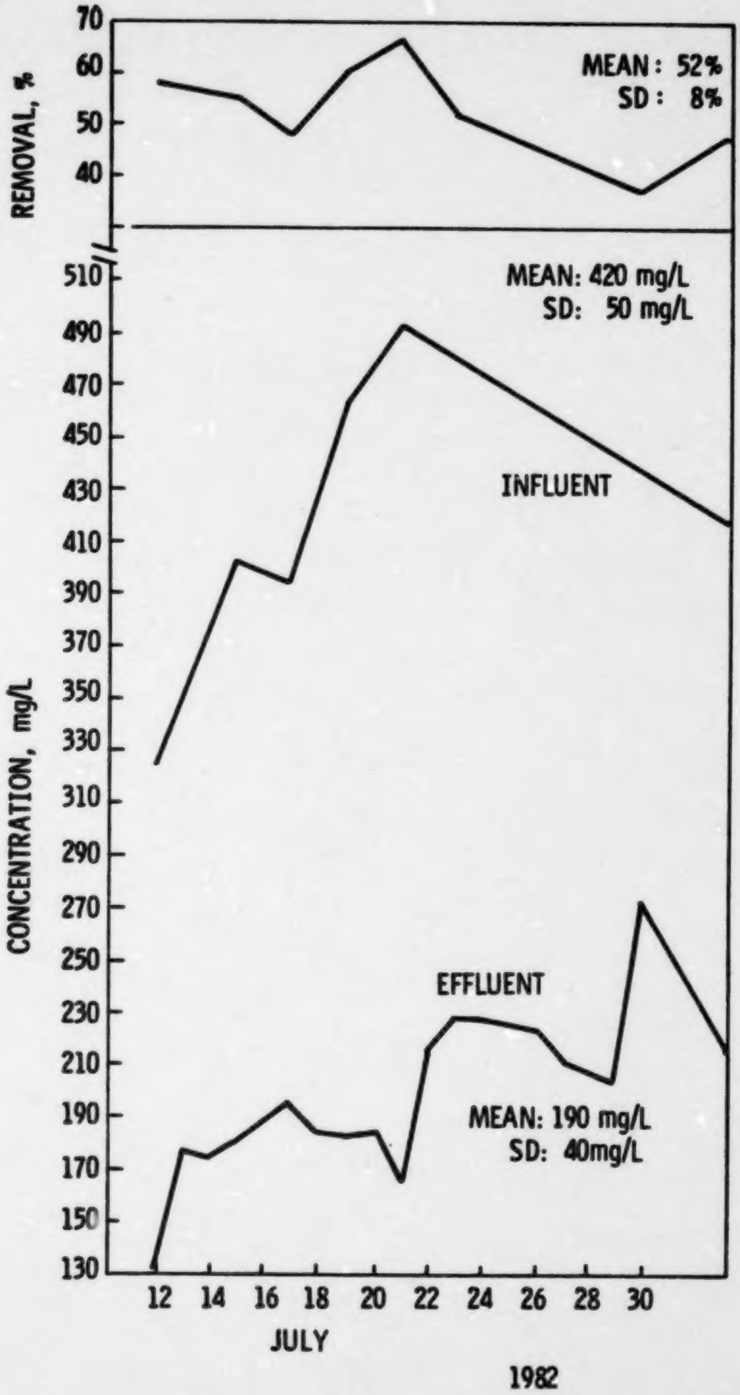

Figure 48. DOC concentration and removal in biological reactor during July.

1,100 mg/L to 1,750 mg/L, averaging 1,380 mg/L (S.D. = 200 mg/L). The effluent COD level varied from 400 mg/L to 740 mg/L, averaging 580 mg/L (S.D. = 100 mg/L). COD removal rates varied from 54% to 63%, averaging 57% (S.D. = 5%) as average. Data after August 1 are not included because of the PAC addition. The influent and effluent COD was 99+% soluble. Although the MLVSS level varied significantly during the test period, the standard deviation (S.D.) was only 5% for COD removal.

BOD_5 and DOC - BOD_5 and DOC were used to supplement the COD data to monitor bioreactor organics removal. Influent and effluent BOD_5 and DOC values along with the corresponding percent removals are presented in Figures 47 and 48, respectively, as well as in Table 29. The average BOD_5 removal was 91% (S.D. = 5%) and the DOC removal was 52% (S.D. = 8%). BOD_5 removal varied from 84% to 98%, and DOC removal varied from 38% to 60%. The DOC removal rate variation might have been due to changes in the organic compounds in the influent water with time.

DO Level and DO Uptake Rate - Dissolved oxygen (DO) and DO uptake rate data are summarized in Table 29 and Figure 49. The DO concentration ranged from 0.5 to 4.5 mg/L, averaging 2.3 mg/L (S.D. = 1.1 mg/L). Except for five days, DO concentrations usually were kept significantly higher than 1.5 mg/L so that growth would not be oxygen-limited. The DO uptake rate varied from 2.5×10^{-6} to 14.7×10^{-6} $kg/m^3/s$, averaging 7.5×10^{-6}, $kg/m^3/s$ (S.D. = 2.2×10^{-6} $kg/m^3/s$). Since the DO uptake rate was consistently greater than zero throughout the entire test period, the reactor microorganism population was active and viable.

Phenols - The activated sludge system achieved excellent removal of phenols as shown in Table 29 and Figure 50. The average influent phenols concentration was 101 mg/L (S.D. = 7.1 mg/L), and the effluent concentration was 6.0 mg/L (S.D. = 3.2 mg/L). Removal

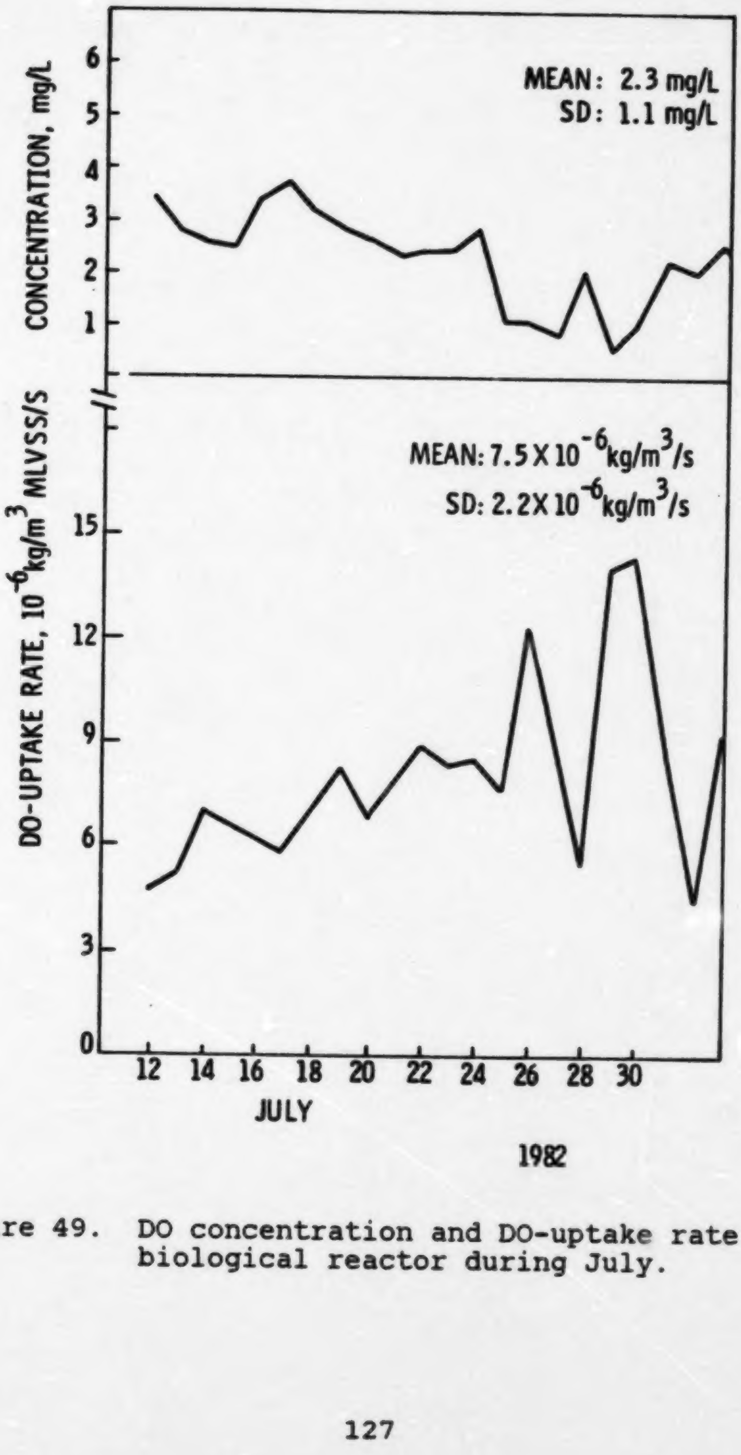

Figure 49. DO concentration and DO-uptake rate in biological reactor during July.

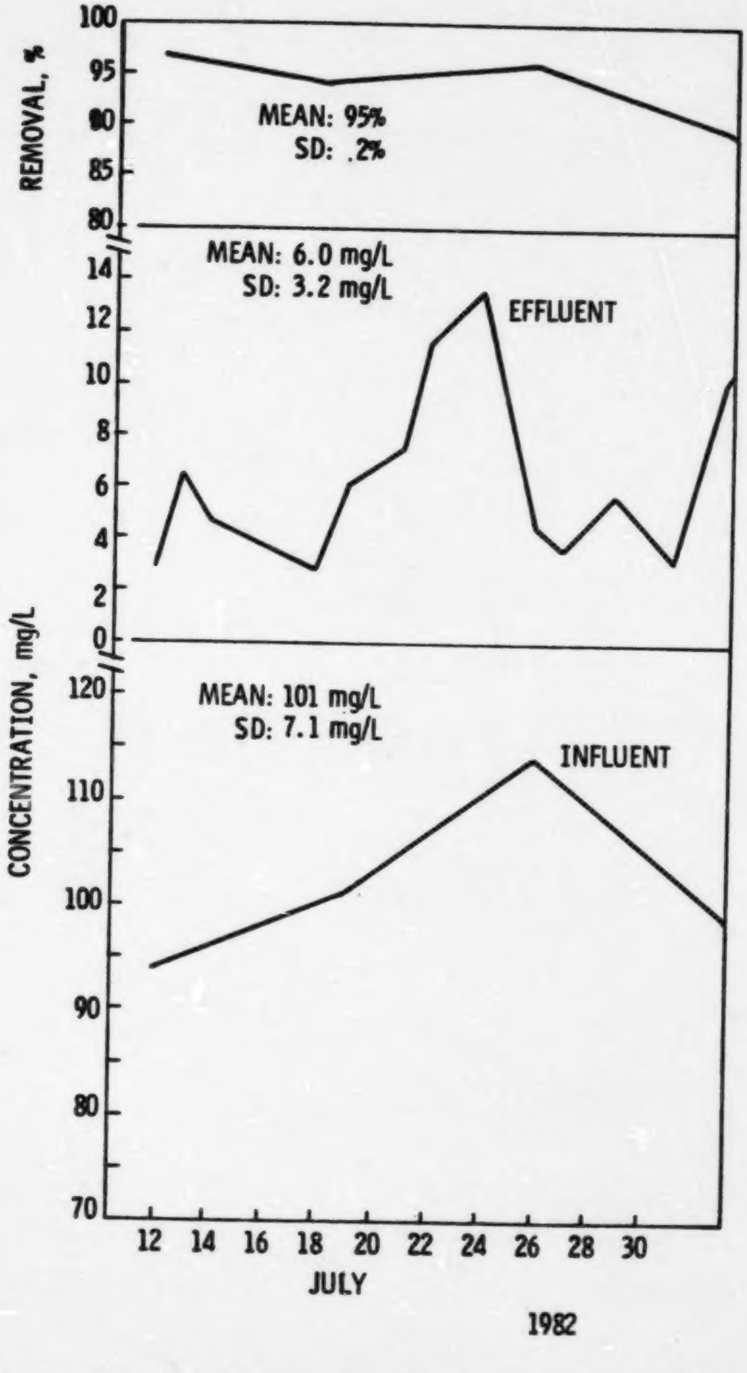

Figure 50. Phenols concentration and removal in biological reactor during July.

for this parameter varied from 93% to 97% and averaged 95% (S.D. = 2%), showing that the system microorganisms could readily degrade phenols.

Ammonia-Nitrogen and Nitrate-Nitrogen - The average influent and effluent ammonia-nitrogen concentrations were 96 mg/L (S.D. = 26 mg/L) and 80 mg/L (S.D. = 10 mg/L), respectively, as shown in Table 29. Ammonia-nitrogen removal by the system was insignificant. In addition, the influent and effluent contained an insignificant amount of nitrate-nitrogen. These low nitrogen concentrations demonstrate that nitrification did not occur in the bioreactor. The bioreactor sludge age of 32 days was considerably in excess of the 10 days generally required to achieve nitrification [5].

pH - The influent pH averaged 8.6 (S.D. = 0.1), and the effluent pH averaged 7.4 (S.D. = 0.3). This indicates that pH decreased approximately 1.2 units across the aeration basin. During the bioreactor operation, influent pH adjustment was not required; the pH in the bioreactor was generally in the desired range of 7.0 to 8.0.

Organic Compounds and Metals - Except for phenols, the concentration of all other organic compounds detected (Table 30) did not change significantly across the biological reactor. Bioreactor influent and effluent metal concentrations were very low (Table 31) and did not affect bioreactor performance.

4.3.4.3 Effect of Powdered Activated Carbon (PAC) Addition on Conventional Activated Sludge System

On July 30, 1982 a quantity of PAC equivalent to a 1,000-mg/L dose was inadvertently added to the steady-state conventional activated sludge system. Prior to this addition, the average COD removal by the bioreactor was 60%. After the PAC addition, COD removals increased to 74%, 68%, and 62% during the first, second, and third day of operation, respectively. Later, this information was used in determining the PAC dosage for a PAC-activated sludge system.

4.3.5 PAC-Activated Sludge Treatment

Activated sludge treatment with powdered activated carbon (PAC) addition was not originally scheduled for testing at Logan Wash. For financial reasons only one biological system, the conventional activated sludge treatment, was to be tested. However, the opportiunity arose to test the PAC-activated sludge treatment, and a system was set up and operated for 16 days. They provide the information reported in this section.

On August 11, 1982, the conventional activated sludge system that had an inadvertant PAC addition on July 30 was converted to a PAC-activated sludge treatment system, and it was operated from August 11 to August 22 using stripped gas condensate as feed. Westvaco Nuchar S-A powdered activated carbon was added batchwise to the bioreactor contents every four hours at the rate of 400 mg/L of feed for the 11 day test duration while an equivalent amount of sludge from the secondary clarifier was simultaneously removed and disposed of. The reactor was operated at a 16-hour hydraulic retention time and at a feed rate of 31.7 cm^3/s (0.5 gal/min).

From August 23 to August 27, this system was operated with increasing PAC dosage rates. The dosage was increased every 24 hours, reaching 1,900 mg/L on the last day of operation. Carbon was added on a batch basis every six hours to maintain the desired concentration. An equivalent amount of sludge from the secondary clarifier was simultaneously removed and wasted. To observe the effect of carbon dosage on pollutant removal, four grab samples (one sample taken every 6 hours) and one 24-hour composite sample of influent and effluent were collected and analyzed for soluble COD, DOC, soluble BOD_5, and phenols.

The results obtained with this PAC-bioreactor from August 11 to August 22 are summarized in Table 32 and discussed below.

Retention Times - The average hydraulic retention time (HRT) was 16 hours, with minimal variation. The average solids retention time (SRT) or sludge age was 44 days. Due to time and financial limitations, the PAC system did operate one complete sludge age cycle indicating a steady-state PAC was not achieved. However, data is presented to indicate removals which can be obtained by a PAC system.

MLSS and MLVSS - MLSS and MLVSS levels varied significantly as shown in Table 32 and Figure 51. This is believed to be due largely to inadequate mixing in the aeration basin which resulted in variations in solids measurements, and to some extent to the batch PAC addition and the sludge wasting schedule. The ratio of MLVSS to MLSS averaged about 0.64.

Chemical Oxygen Demand - Soluble COD was the key parameter used to monitor bioreactor performance. Influent and effluent COD values, along with corresponding percent removals, are presented in Figure 52. The influent COD varied from 1,600 mg/L to 2,100 mg/L, averaging 1,700 mg/L (S.D. = 140 mg/L). The effluent COD varied from 410-870 mg/L and averaged 530 mg/L (S.D. = 120 mg/L). The COD removal rate varied from 54% to 74%, averaging 70% (S.D. = 5%). COD removal was greater than 65% during the first ten days of operation, but it dropped significantly in the last two days, from 72% to 54%.

TABLE 32. PAC BIOREACTOR PERFORMANCE DATA SUMMARY[a,b]

Parameter	Number of analyses performed	Influent concentration, mg/L		Number of analyses performed	Effluent concentration, mg/L		Percent removal[c]	
		Range	Average		Range	Average	Range	Average
Soluble COD	19	1,600-2,100	1,700	20	410-870	530	54-74	70
DOC	5	370-510	430	5	140-190	170	50-65	59
Soluble BOD_5	2	670-730	700	3	13-110	60	94-98	96
Phenols	5	84-106	94	5	0.93-2.00	1.35	98-99	99
NH_3-N	8	82-120	100	6	85-110	94	(-15)-18	6
NO_3-N	4	0.4-1.01	0.62	3	0.0-0.50	0.22		
pH	60	8.3-8.7[d]	8.5[d]	60	7.1-7.5[d]	7.3[d]	NA	NA

NA = not applicable.

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[a] PAC dosage: 400 mg/L.

[b] Steam stripper operated according to Table 23.

[c] Numbers in parentheses indicate increase.

[d] Standard pH units.

Parameter	Number of analysis performed	Mixed liquor characteristics	
		Range	Average
TSS, mg/L	19	3,600-5,900	4,800
VSS, mg/L	19	1,900-4,200	3,200
DO, mg/L	~66	3.7-5.0	4.5
DO uptake rate, 10^{-6} kg/m^3/s	9	3.6-8.3	6.4

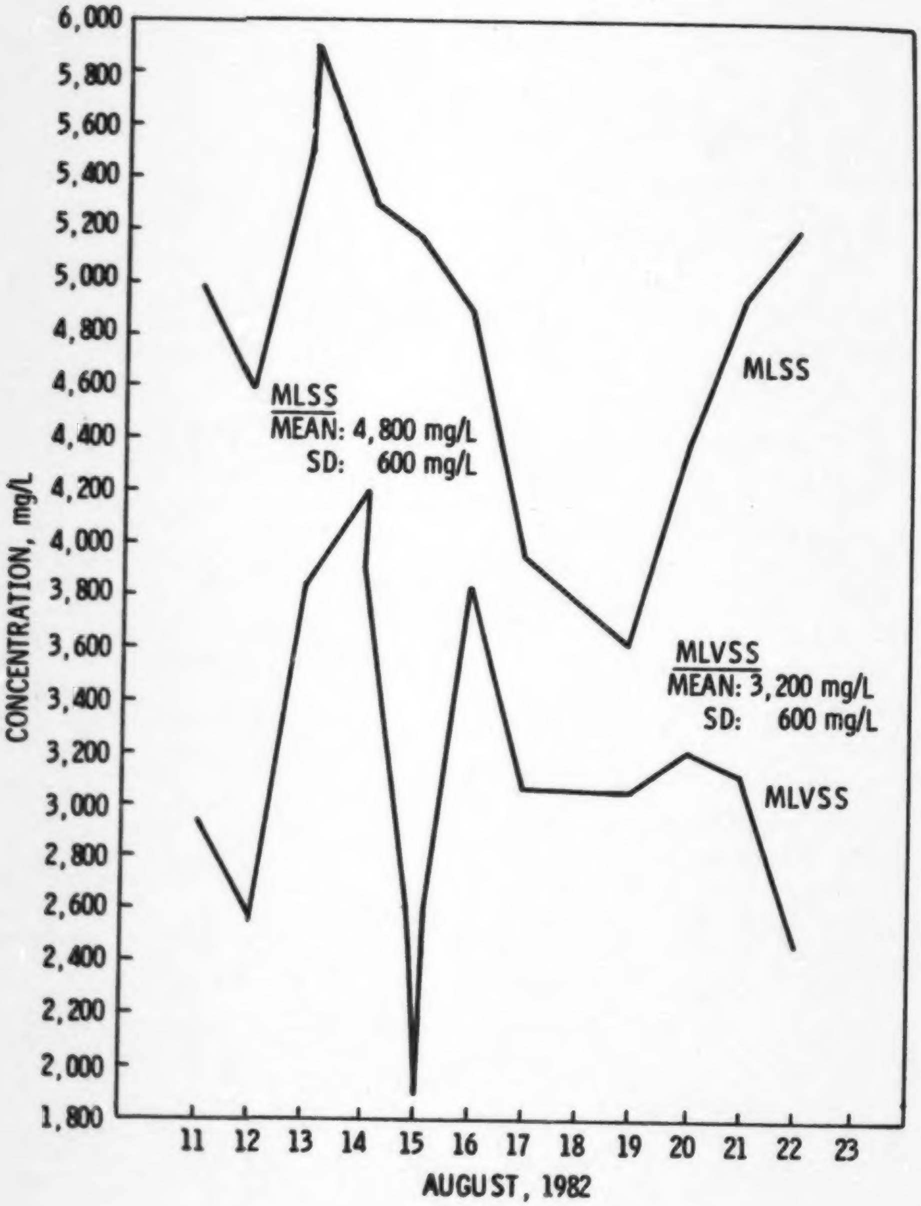

Figure 51. MLSS and MLVSS concentration in PAC bioreactor, August 11 through August 22.

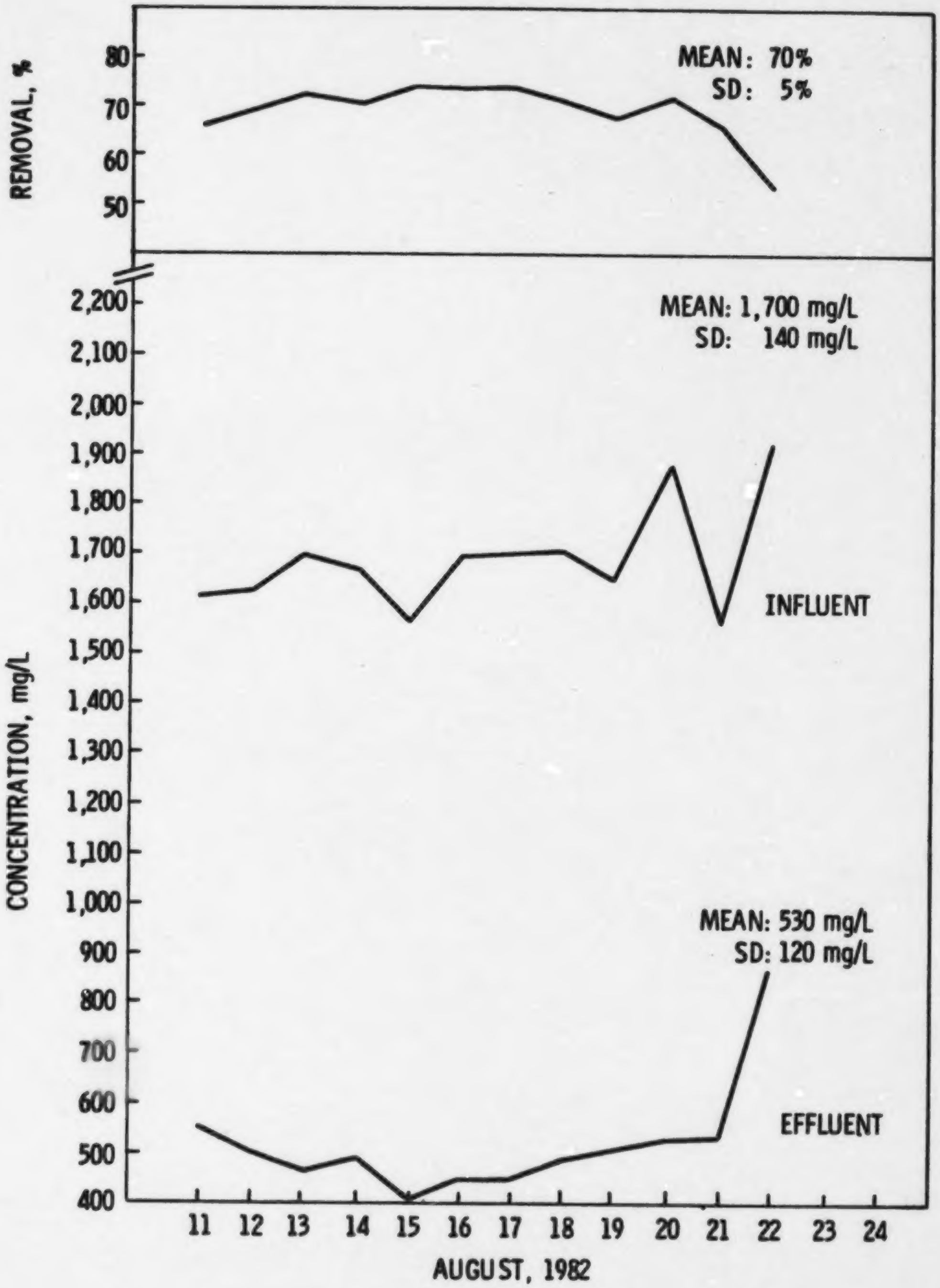

Figure 52. Soluble COD concentration and removal in PAC bioreactor, August 11 through August 22.

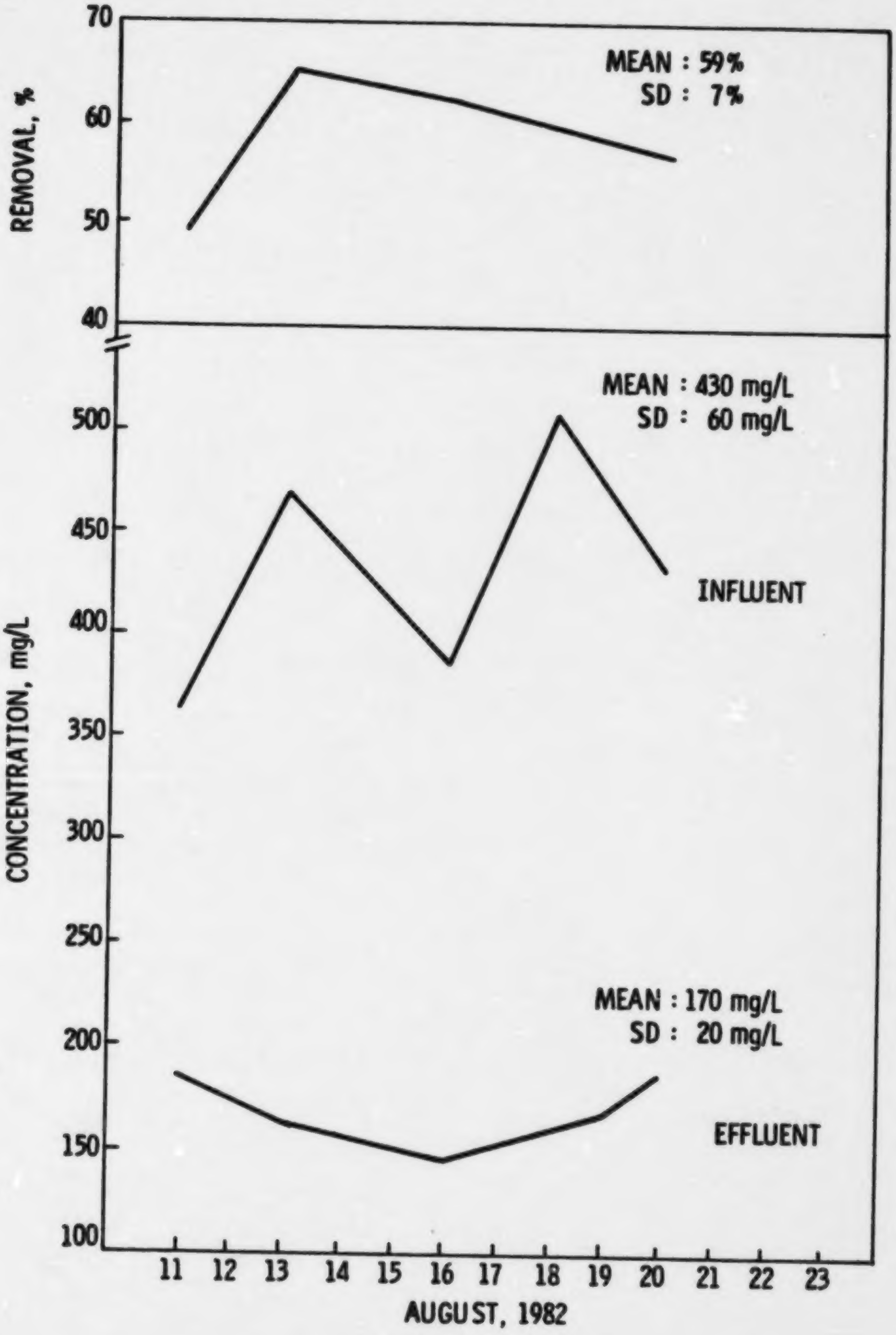

Figure 53. DOC concentration and removal in PAC bioreactor, August 11 through August 22.

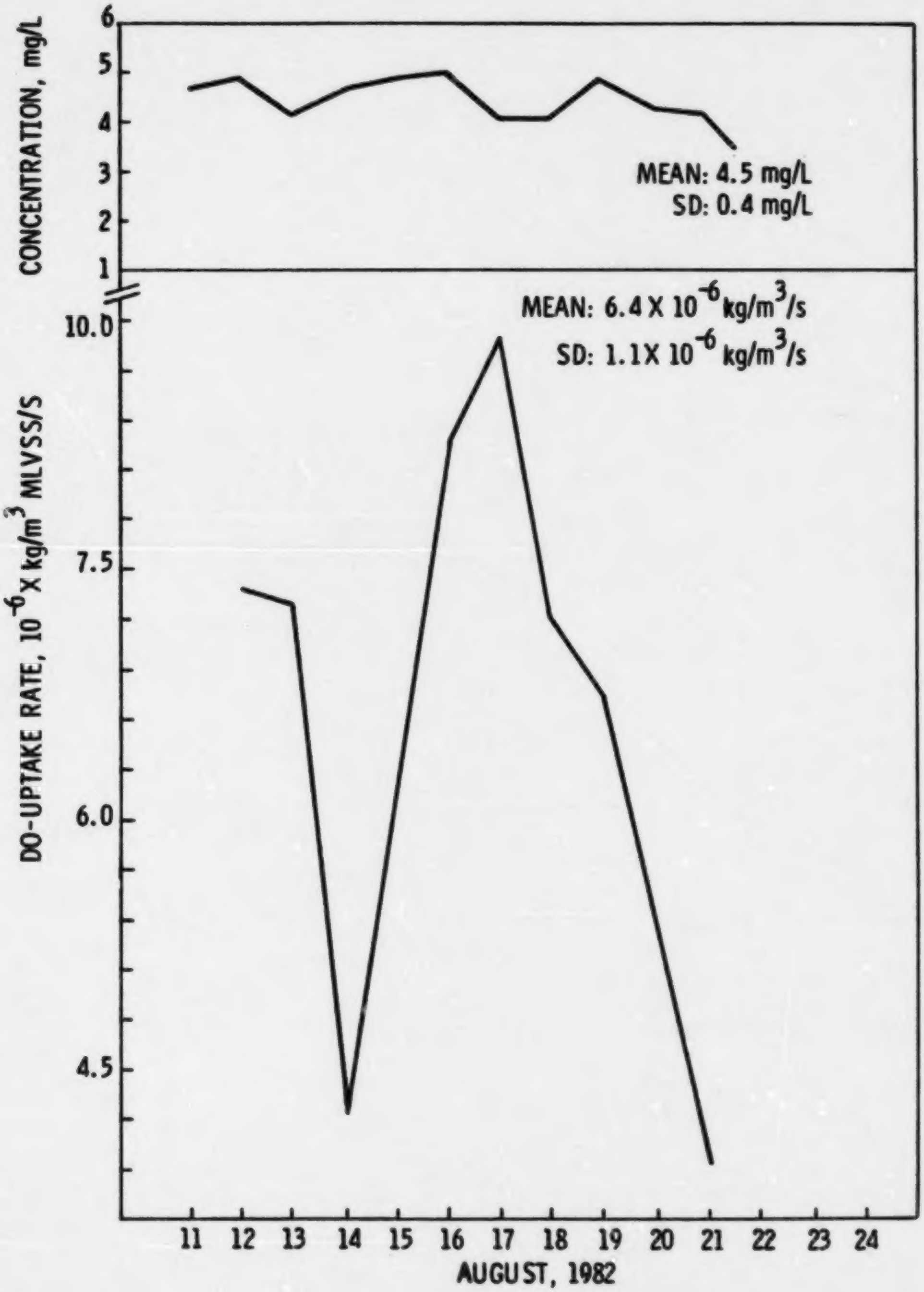

Figure 54. DO concentration and DO-uptake rate in PAC bioreactor, August 11 through August 22.

DOC and BOD_5 - DOC and BOD_5 data were collected to supplement the COD data in monitoring bioreactor performance. Influent and effluent DOC values, along with corresponding percent removals, are plotted in Figure 53. As shown in Table 32 and Figure 53, DOC removal varied from 50% to 65%, averaging 59% (S.D. = 7%). DOC removal gradually decreased with time. Soluble BOD_5 removal averaged 96%, and an effluent BOD_5 concentration as low as 13 mg/L was achieved.

DO Concentration and DO Uptake Rate - Dissolved oxygen (DO) concentration and DO uptake rate results are summarized in Table 32 and Figure 54. The DO concentration ranged from 3.7 to 5.0 mg/L, and averaged 4.5 mg/L (S.D. = 0.4 mg/L), assuring aerobic conditions in the bioreactor. The DO uptake rate varied from 3.6×10^{-6} to 8.3×10^{-6} kg/m^3/s, averaging 6.4×10^{-6} kg/m^3/s (S.D. = 1.1×10^{-6} kg/m^3/s). DO uptake data indicate that the reactor microorganism population was viable during the test period. During the last four days of operation, the DO uptake rate dropped significantly, from 10×10^{-6} to 4.3×10^{-6} kg/m^3/s, indicating a gradual decrease in biological activity. This could have resulted from a decrease in the biological solids and an increase in the PAC solids in the reactor as PAC was added and sludge was wasted.

Phenols - As shown in Table 32, the average removal of phenols was 99% (S.D. = 0.4%); the effluent contained less than 2 mg/L of phenols. This demonstrates excellent capability of the PAC-activated sludge system for removal of phenols from stripped gas condensate.

Ammonia-Nitrogen and Nitrate-Nitrogen - The average influent and effluent ammonia-nitrogen concentrations were 100 mg/L (S.D. = 12 mg/L) and 94 mg/L (S.D. = 6 mg/L), respectively, as shown in Table 32. Thus, ammonia-nitrogen removal by the PAC system was insignificant. The influent and effluent also contained an insignificant amount of nitrate-nitrogen. These low nitrogen concentrations demonstrate that nitrification did not occur during the short bioreactor operation.

pH - Influent pH averaged 8.5 (S.D. = 0.1), whereas effluent pH averaged 7.3 (S.D. = 0.1). Thus, pH dropped by 1.2 units across the aeration basin. During the test period, influent pH adjustment was not required. The pH in the bioreactor ranged from 7.1 to 7.5 standard units.

The results of increasing PAC dosage experiments (August 23 through 27) are summarized in Table 33, and removal rates are plotted in Figure 55. These data show that removal of DOC, soluble COD and BOD_5, and phenols increases with an increase in PAC dosage as expected, but the incremental increases are not proportional to the dosage increase.

4.3.6 Sand Filtration

The purpose of the sand filters was to remove suspended solids from the secondary clarifier effluent and thus prevent clogging of the granular activated carbon (GAC) columns used in subsequent treatment of the effluent. The sand filters were used so that only one filter was in operation at a time. Water feed rate to the 1.7-m (5.5 ft) deep sand filters was 31.5 cm^3/s (0.5 gal/min) from July 12-27 and reduced to 25.2 cm^3/s (0.4 gal/min) from July 28 to August 11. The filter was backwashed as needed, generally every 16 to 20 hours. The performance data for the sand filters are presented in Table 34.

The data show that except for July 19 and 21, the sand filter effluent had a TSS level equal to or lower than 20 mg/L. This indicates that the sand filter successfully removed suspended

TABLE 33. PAC BIOREACTOR PERFORMANCE DATA SUMMARY[a] - INCREASING PAC DOSAGE OPERATION

PAC dosage, mg/L	Soluble COD				DOC			
	Number of analyses performed	Concentration, mg/L		Percent removal	Number of analyses performed	Concentration, mg/L		Percent removal
		Influent	Effluent			Influent	Effluent	
400[b]	-[b]	1,700	530	70	-[b]	430	170	59
475	5[c]	1,800	610	67	5[c]	390	150	62
950	5[c]	1,600	330	80	5[c]	370	110	69
1,425	5[c]	1,600	300	82	5[c]	380	83	78
1,900	5[c]	1,700	240	86	5[c]	410	65	84
	Soluble BOD_5				Phenols			
	Number of analyses performed	Concentration, mg/L		Percent removal	Number of analyses performed	Concentration, mg/L		Percent removal
		Influent	Effluent			Influent	Effluent	
400[b]	-[b]	700	56	96	-[b]	94	1.35	99
475	3[d]	750	85	89	2[e]	84	1.17	99
950	3[d]	860	81	91	2[e]	92	0.38	100
1,425	3[d]	730	49	93	2[e]	86	0.13	100
1,900	3[d]	750	40	95	2[e]	82	0.07	100

[a] All concentration and removal data are averages of all analyses performed for the parameter of interest.

[b] Performance data are taken from Table 32 for the 400 mg/L PAC dosage and are averages of results collected over a 10-day period.

[c] 4 grabs and 1 composite sample taken over test period at each condition.

[d] 2 grabs and 1 composite sample taken over test period at each condition.

[e] 2 grabs samples.

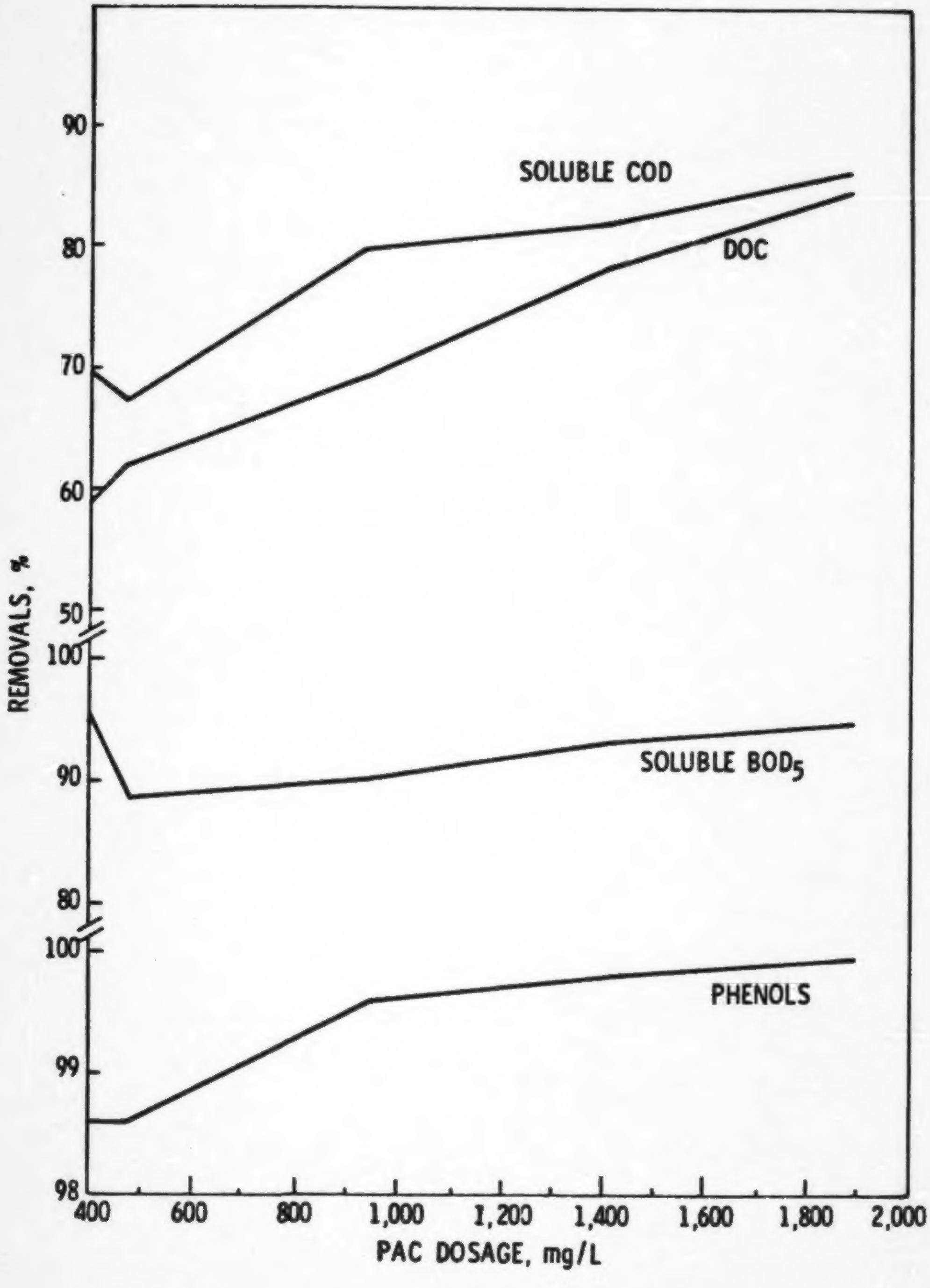

Figure 55. PAC bioreactor removal performance with increasing dosage.

TABLE 34. SAND FILTER PERFORMANCE DATA SUMMARY

Date, 1982	Type of sample[a]	TSS concentration, mg/L		Percent removal
		Influent	Effluent	
7/12	G	58	NS[b]	-
7/12	G	87	NS	-
7/12	G	53	NS	-
7/14	G	43	NS	-
7/15	G	14	<5	>64
7/16	G	15	<5	>67
7/17	G	70	NS	-
7/17	G	200	NS	-
7/18	G	43	NS	-
7/18	C	172	NS	-
7/19	G	124	9	83
7/19	G	-[c]	84	-
7/20	C	93	NS	-
7/21	G	233	75	68
7/22	C	25	NS	-
7/24	G	-[c]	7	-
7/25	G	13	<5	>62
7/25	C	114	NS	-
7/26	C	100	NS	-
7/27	C	154	NS	-
7/29	C	381	NS	-
7/30	C	390	NS	-
7/31	G	70	14	80
8/1	C	33	NS	-
8/2	C	53	NS	-
8/3	C	27	NS	-
8/4	G	33	13	61
8/5	C	29	NS	-
8/7	C	29	NS	-
8/8	G	64	13	80
8/9	C	30	NS	-
8/10	C	61	NS	-
8/10	G	78	20	74
Average	-	93	23	71

[a] G - grab
C - composite.

[b] NS - not sampled.

[c] Sample lost.

solids from the secondary clarifier effluent. The reasons for the high effluent concentrations obtained on July 19 and 21 may be attributed to high influent TSS concentration.

4.3.7 GAC Adsorption

Granular activated carbon (GAC) adsorption tests were conducted on two types of effluents: (1) the stream stripper effluent, and (2) the effluent from the secondary clarifier of the conventional activated sludge treatment system after sand filtration.

Tests with GAC were conducted using the two carbon columns shown in Figure 56.

The columns were operated in a downflow mode. Column influent and effluent samples were taken for performance evaluation at the locations shown in Figure 56.

4.3.7.1 GAC Adsorption of Stripper Effluent

Treatment of stripper effluent with granular activated carbon (GAC) was not scheduled for testing at Logan Wash. However, to maximize the benefit of the Logan Wash trial results, such testing was conducted simultaneously with the conventional activated sludge treatment. The capacity of the steam stripper was adequate to supply both treatment processes with stripper effluent.

Stripper effluent was passed directly through the columns (i.e., no prefiltration was used) at an average flow rate of 41.7 cm^3/s (0.66 gal/min) ranging from 39.2 to 44.2 cm^3/s. This flow rate corresponds to a hydraulic loading rate of 0.22 $m^3/s \cdot m^2$ (3.3 gpm/ft^2) and an empty bed contact time of 660 s per columns. Grab samples of the stripper effluent (which was the column 1 influent), the column 1 effluent, and the column 2 effluent were collected

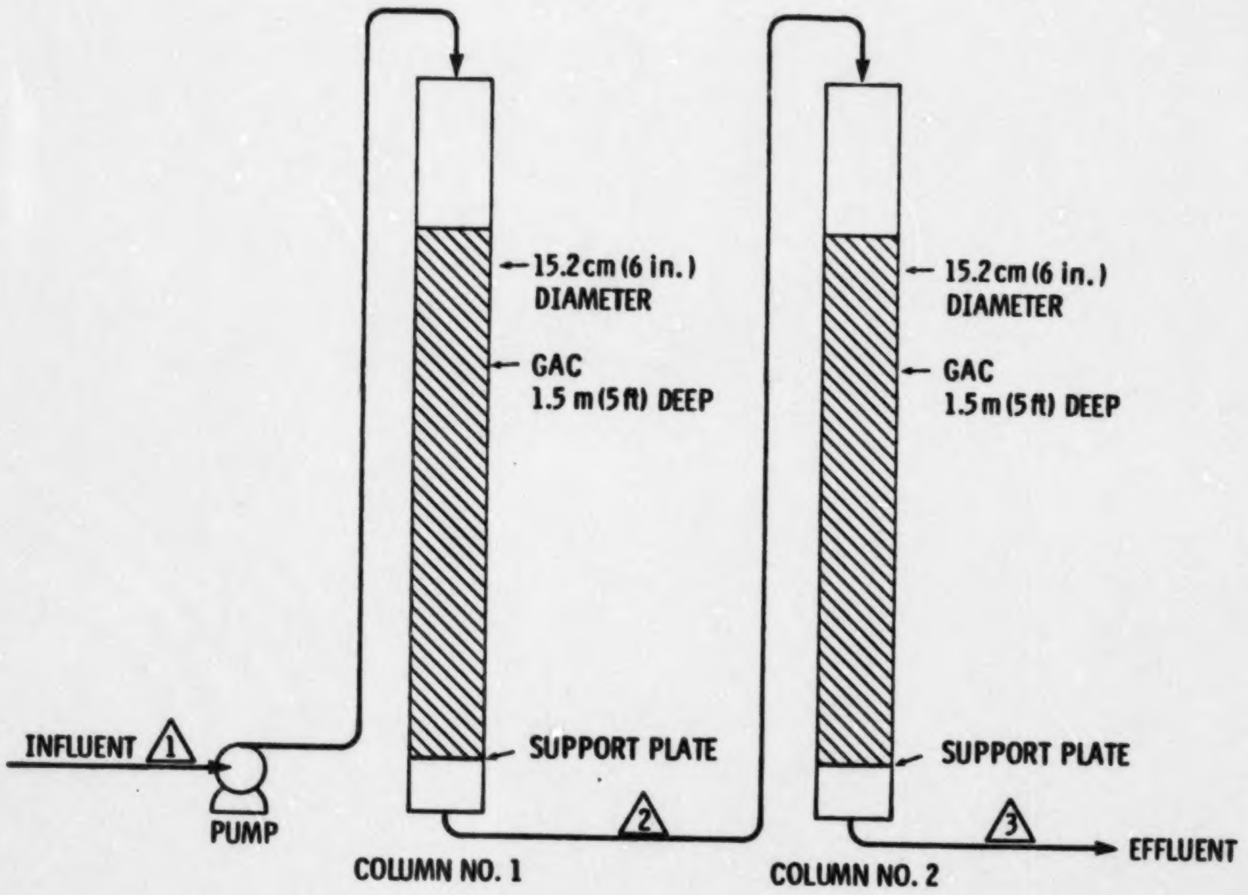
15.2cm (6 in.)
DIAMETER
GAC
1.5 m (5 ft) DEEP
SUPPORT PLATE
15.2cm (6 in.)
DIAMETER
GAC
1.5 m (5 ft) DEEP
SUPPORT PLATE
INFLUENT
1
PUMP
2
3
EFFLUENT
COLUMN NO. 1
COLUMN NO. 2

Figure 56. Schematic diagram of carbon column system and sample points used for GAC adsorption tests.

approximately twice per day and analyzed for soluble COD, DOC, phenols, and soluble BOD_5. Analytical results are presented in Table 35. The columns operated continuously for the duration of the stripper effluent run (233 hr) and did not require backwashing.

Soluble COD breakthrough curves for columns 1 and 2 are plotted in Figure 57. The curves are not very steep, and breakthrough is reached immediately in both columns, indicating a relatively poor adsorption for some of the components. Soluble COD concentrations in the column influent ranged from 490 mg/L to 970 mg/L and averaged approximately 800 mg/L during the test period. Soluble COD removals were equal to or greater than 90% for only the first 7.2 m^3 throughput (48 hours) with average influent and No. 2 effluent concentrations of 630 mg/L and 60 mg/L, respectively. DOC concentrations in the column influent during the test period ranged from 190 mg/L to 250 mg/L and averaged approximately 210 mg/L. DOC removals were equal to or greater than 86% for the first 9 m^3 throughput (60 hours) with average influent and No. 2 effluent concentrations of 210 mg/L and 24 mg/L, respectively.

During the test period, influent phenols concentrations varied from 69 mg/L to 96 mg/L and averaged 82 mg/L. Initial removal of phenols was high (approximately 99%). However, a significant increase (breakthrough) in phenols concentration from column 1 occurred after 14.4 m^3 throughput (95 hours) and from column 2 after 25.2 m^3 throughput (168 hours). Influent soluble BOD_5 concentrations varied from 240 mg/L to 410 mg/L during the test period with 340 mg/L as average. Soluble BOD_5 removal rate was greater than 84% during the first 18 m^3 throughput (120 hours) with the carbon column average effluent soluble BOD_5 level at 50 mg/L.

TABLE 35. PERFORMANCE DATA FOR CARBON COLUMN TESTING OF GAS CONDENSATE STEAM STRIPPER EFFLUENT, JUNE 22-JULY 2, 1982[a]

Throughput volume, m^3	Concentration, mg/L					
	Soluble COD			DOC		
	Stripper effluent	Column 1 effluent	Column 2 effluent	Stripper effluent	Column 1 effluent	Column 2 effluent
<0.1	660	100	-[c]	210	11	-[b]
1.8	510	40	-[c]	200	28	-[b]
3.6	580	57	-[c]	200	29	-[b]
5.4	770	86	42	210	33	19
7.2	620	100	64	200	39	27
8.1	610	130	83			
9.0	-[b]	150	87	210	50	30
10.8	640	200	91	200	72	35
12.6	710	310	110	190	85	37
14.4	720	380	110	200	120	41
16.2	660	510	140	190	160	50
17.1	670	530	140			
18.0	670	470	140	200	150	34
19.8	680	530	200	220	170	49
21.6	680	540	220	210	200	78
23.4	800	570	280			
24.3	970	710	390			
25.2	800	560	290	220	190	100
27.0	490	360	280			
27.9				220	220	140
28.8	760	700	470	250	220	150
30.6	680	730	570			
31.5				240	210	160
32.4	770	810	510	250	230	170
34.2	890	770	630			
35.1	960	720	590			

Throughput volume, m^3	Concentration, mg/L					
	Phenols			Soluble BOD_5		
	Stripper effluent	Column 1 effluent	Column 2 effluent	Stripper effluent	Column 1 effluent	Column 2 effluent
<0.1	80	0.026	-[c]	-[b]		
1.8	69	<0.005	-[c]			
3.6	74	<0.005	-[c]			
5.4	80	<0.005	<0.005	350	35	
7.2	81	0.025	<0.005	280	90	39
8.1						
9.0	70	0.06	<0.005			
10.8	72	10	<0.005	240	81	50
12.6						
14.4	70	44	<0.005	370	170	56

(continued)

TABLE 35 (continued)

Throughput volume, m^3	Concentration, mg/L					
	Phenols			Soluble BOD_5		
	Stripper effluent	Column 1 effluent	Column 2 effluent	Stripper effluent	Column 1 effluent	Column 2 effluent
16.2						
17.1						
18.0	89	87	0.14	330	230	53
19.8						
21.6	80	83	0.14	300	290	
23.4						
24.3						
25.2	90	83	1.06	410	350	
27.0						
27.9	96	96	36	310	380	230
28.8	93	90	59	390		
30.6						
31.5	96	104	110	330		
32.4	87	98	109	410	370	
34.2						
35.1						

[a] Steam stripper operated according to Table 23.

[b] Blanks indicate that either no sample was taken or sample was lost.

[c] Column 2 not in operation for initial 30.5 hours.

4.3.7.2 GAC Adsorption of Biologically Treated Effluent

Two tests were conducted using the two GAC columns in series to treat effluent from the conventional biological treatment system. The two carbon columns, were preceded by two sand filters. Two tests were conducted to study the effects of different contact times on removals. The operating conditions for each are shown in Table 36. Grab samples of the filtered biological effluent (i.e., carbon column 1 influent) and carbon column 1 and 2 effluents were collected once a day for soluble COD analysis and approximately once every two days for DOC, phenols, and soluble BOD_5 analyses. The results of these analyses are shown in Tables 37 and 38 for tests 1 and 2, respectively. The carbon

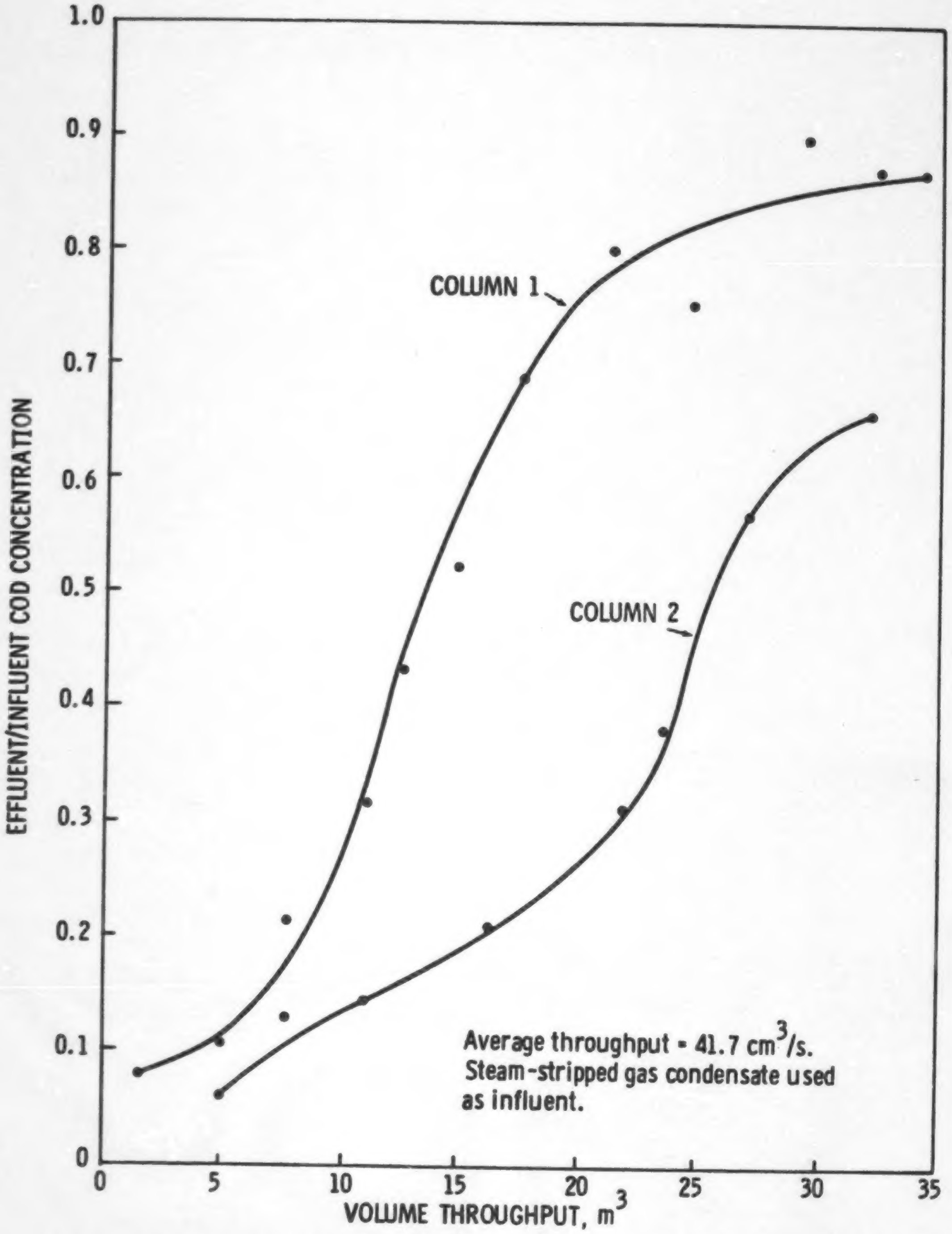

Figure 57. Soluble COD breakthrough curves for GAC columns 1 and 2 using stripped gas condensate as influent.

TABLE 36. OPERATING CONDITIONS FOR GAC COLUMN TESTS WITH BIOLOGICALLY TREATED EFFLUENT

Parameter, units		Test 1	Test 2
Average wastewater influent rate: cm^3/s (gal/min)		31.5 (0.5)	25.2 (0.4)
Hydraulic loading rate: $m^3/s \cdot m^2$ (gpm/ft^2)		1.63×10^{-3} (2.4)	1.36×10^{-3} (2.0)
Empty bed contact time, s:	Column 1	930	1,120
	Columns 1 and 2	1,860	2,240

columes were operated continuously for the duration of the run (Test 1 = 309 hr; Test 2 = 275 hr) and did not require backwashing.

Soluble COD breakthrough curves for columns 1 and 2 and tests 1 and 2 are plotted in Figures 58 and 59, respectively. In both tests column 1 curves are not very steep. Comparison of column 2 curves for both tests indicates that at the lower feed rate or longer contact time, the time until breakthrough was longer in test 2 than in test 1.

During test 1, column influent soluble COD concentrations ranged from 400 mg/L to 670 mg/L and averaged approximately 560 mg/L. Soluble COD removals were equal to or greater than 90% for the first 22.2 m^3 throughput (200 hours) with average influent and No. 2 effluent concentrations of 520 mg/L and 20 mg/L, respectively. During the test period, column influent DOC concentrations ranged from 180 mg/L to 230 mg/L and averaged 200 mg/L. DOC removals were equal to or greater than 84% for the first 27.5 m^3 throughput (247 hours) with average influent and No. 2 effluent concentrations of 200 mg/L and 20 mg/L, respectively. Phenols removal was greater than 97% during the test period with average influent and #2 effluent concentrations of 7 mg/L and 0.03 mg/L, respectively.

TABLE 37. PERFORMANCE DATA FOR CARBON COLUMN TESTS WITH BIOLOGICALLY TREATED GAS CONDENSATE EFFLUENT TEST 1[a,b]: JULY 13-JULY 27, 1982

Through-put volume, m^3	Concentration, mg/L					
	Soluble COD			DOC		
	Filtered biological effluent	Column 1 effluent	Column 2 effluent	Filtered biological effluent	Column 1 effluent	Column 2 effluent
<0.1	460	4	4	180	8	4
0.7						
2.1	520	5	5	180	13	11
4.5	400	11	15			
7.2	470	9	6			
9.9	520	72	15			
12.6	530	210	22	190	74	17
15.2	500	190	24			
17.0	550	190	16	190	73	18
19.6	600	260	47			
22.2	670	270	43	220	95	26
24.8	670	370	86			
27.5	660	490	120	230	160	37
30.1	630	510	180			
32.6	650	560	320			
35.4	630	570	340	210	190	130

(continued)

TABLE 37 (continued)

Throughput volume, m^3	Concentration, mg/L					
	Phenols			Soluble BOD_5		
	Filtered biological effluent	Column 1 effluent	Column 2 effluent	Filtered biological effluent	Column 1 effluent	Column 2 effluent
<0.1	7.3	0.10	0.050			
0.7	5.2					
2.1	4.3	0.10	0.032			
4.5						
7.2						
9.9						
12.6	2.8	0.023	0.077	100	23	7
15.2						
17.0	6.7	0.055	<0.005			7
19.6						
22.2	11	0.42	0.015			
24.8						
27.5	14	5.1	0.010	92	92	18
30.1						
32.6						
35.4	3.6	3.44	0.037	43	140	33

[a] Blanks indicate that either no sample was taken or the sample was lost.

[b] Steam stripper operated according to conditions in Table 23.

TABLE 38. PERFORMANCE DATA FOR CARBON COLUMN TESTING OF BIOLOGICALLY TREATED GAS CONDENSATE EFFLUENT TEST 2[a,b]: JULY 29-AUGUST 9, 1982

Through-put volume, m^3	Concentration, mg/L					
	Soluble COD			DOC		
	Filtered biological effluent	Column 1 effluent	Column 2 effluent	Filtered biological effluent	Column 1 effluent	Column 2 effluent
1.0	640	32	24	200	15	9
2.1	710	27	16			
3.2	740	78	57			
5.3	520	47	34	120	17	14
6.3	470	49	36			
7.5	470	33	6			
9.7	520	78	12			
11.8	610	140	17			
13.9	600	240	19			
15.1	650	310	40			
16.1	670	380	48			
17.2			52			
17.5				200	92	16
18.3	580	340	46			
19.4	590	400	89			
20.5	590	360	88	300	180	26
21.5	590	400	130			
22.6	680	480	150			
23.7		410	170			
24.8	630	500	180			

(continued)

TABLE 38 (continued)

Throughput volume, m^3	Concentration, mg/L					
	Phenols			Soluble BOD_5		
	Filtered biological effluent	Column 1 effluent	Column 2 effluent	Filtered biological effluent	Column 1 effluent	Column 2 effluent
1.0	5.6	0.009	0.010			
2.1						
3.2						
5.3	3.1	<0.005	0.013	88	22	15
6.3						
7.5						
9.7						
11.8						
13.9						
15.1						
16.1						
17.2						
17.5	9.2	0.13	0.040			
18.3						
19.4						
20.5	3.9	0.1	0.032		63	9
21.5						
22.6						
23.7						
24.8						

[a] Blanks indicate that either no sample was taken or sample was lost.

[b] Steam stripper operated according to Table 23.

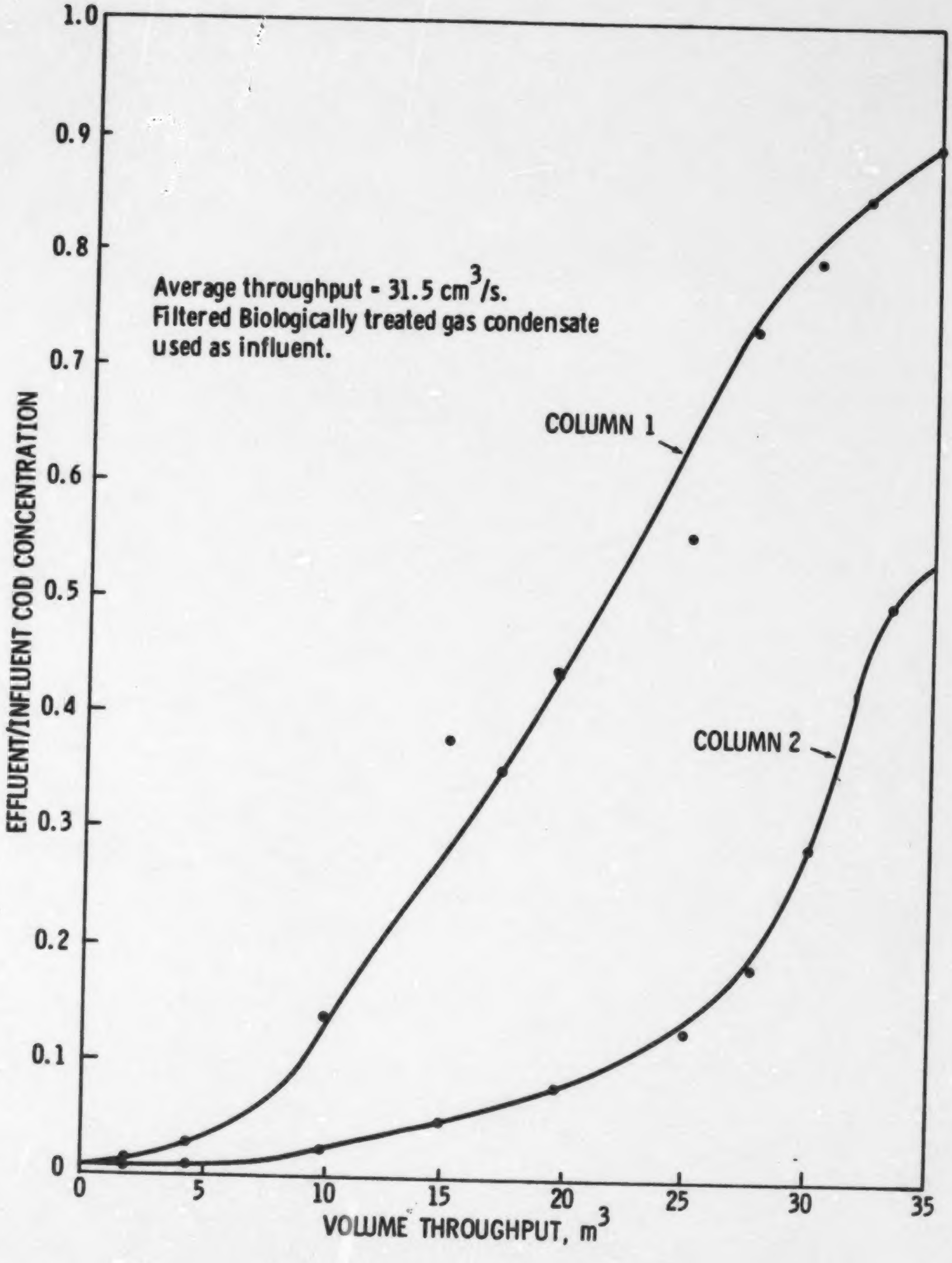

Figure 58. Soluble COD breakthrough curves for GAC columns 1 and 2 using filtered biologically treated effluent, Test 1.

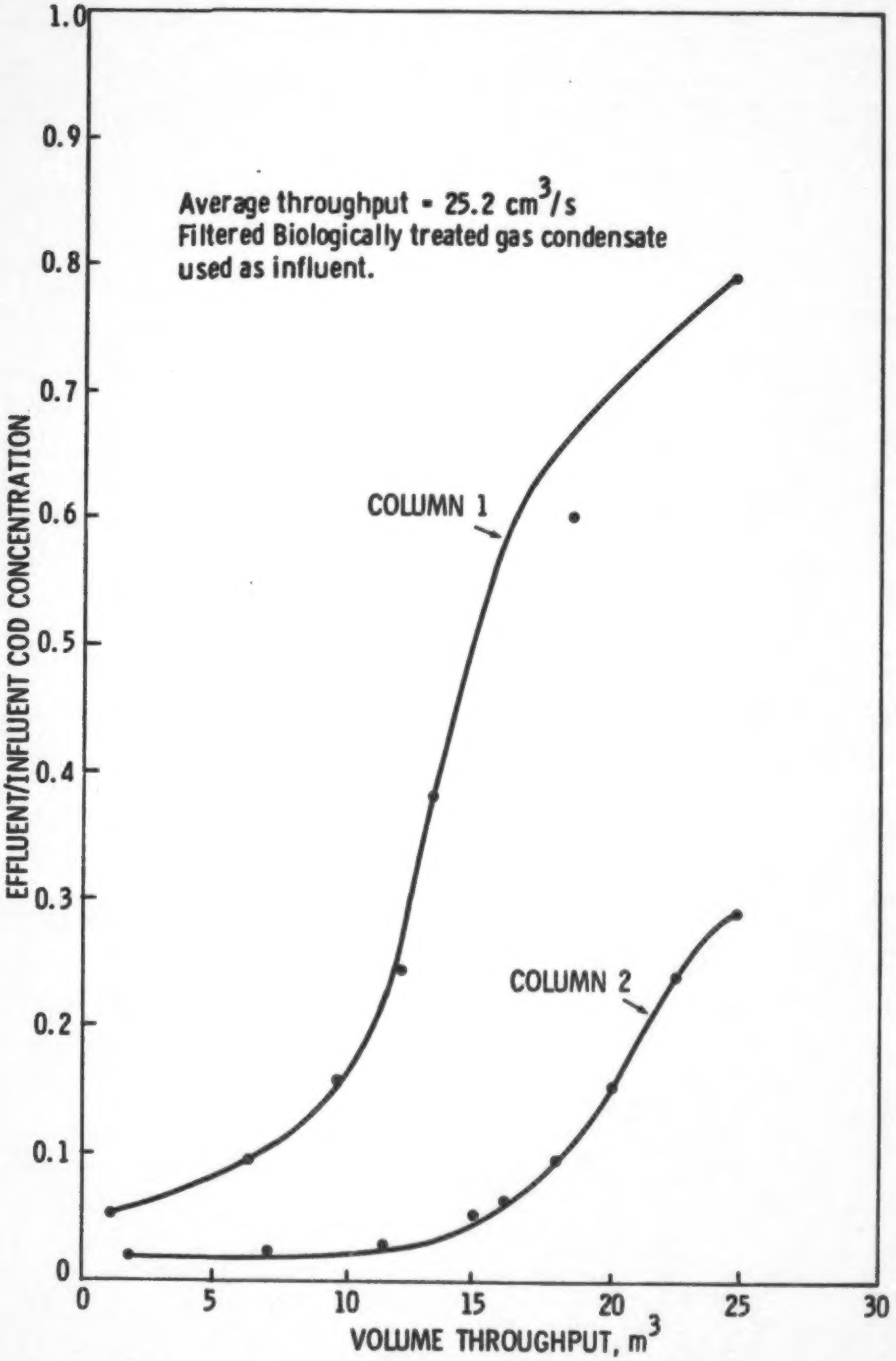

Figure 59. Soluble COD breakthrough curves for GAC columns 1 and 2 using filtered biologically treated effluent, Test 2.

During test 2, soluble COD concentrations in the column influent ranged from 470 mg/L to 740 mg/L and averaged approximately 600 mg/L. Soluble COD removals were equal to or greater than 92% for the first 18.3 m^3 throughput (203 hours) with average influent and #2 effluent concentrations of 600 mg/L and 30 mg/L, respectively. During the test period, column influent DOC concentrations ranged from 120 mg/L to 300 mg/L and averaged 210 mg/L. DOC removals were equal to or greater than 92% for the first 17.5 m^3 throughput (227 hours) with average influent and #2 effluent concentrations of 210 mg/L and 15 mg/L, respectively. Phenols removal was greater than 99% during 20.5 L throughput with average influent and #2 effluent concentrations of 5.5 mg/L and 0.02 mg/L, respectively.

The spent carbon was analyzed according to RCRA requirements. The results of these analyses indicated that the spent carbon was nonhazardous.

During the first eight hours of Test 2 GAC column operation, 8 hr composite samples of column 1 influent and column 2 effluent were collected and analysed for metals and organics using GC/MS. The analytical results, presented in Tables 39 and 40, indicate that metals concentrations were very low and about the same in both the influent and the effluent. Eight organic compounds were present in the influent at concentrations ranging from 2.5 to 17 mg/L. Of these, phenols and 3-methyl-2-cyclopenten-1-one were completely removed. The concentrations of the others did not change significantly.

4.3.8 Overall Treatment

Filter coalescing, steam stripping, conventional activated sludge treatment, sand filtration, and GAC adsorption comprised the overall treatment scheme for the gas condensate. The scheme was very effective in removing ammonia, organics, sulfide, alkalinity, and

TABLE 39. CARBON COLUMN PERFORMANCE DATA FOR METALS[a]

	Concentration, mg/L	
Metal	Column 1, influent	Column 2, effluent
Ag	<0.19	<0.19
Al	4.53	0.23
As	<0.01	0.03
B	0.42	0.45
Ba	<0.01	0.04
Be	<0.01	<0.01
Ca	6	13.9
Cd	<0.01	<0.01
Co	<0.04	<0.04
Cr	<0.02	<0.02
Cu	<0.03	<0.03
Fe	0.28	0.20
Hg	<0.01	<0.01
K	<2.6	<2.6
Mg	2.32	3.38
Mn	0.02	0.03
Mo	<0.05	<0.05
Na	11.8	14.7
Ni	<0.08	<0.08
Pb	<0.1	<0.1
Sb	<0.38	<0.38
Se	<0.01	<0.01
Sn	<0.5	0.94
Sr	0.02	0.20
Ti	<0.02	<0.02
V	<0.03	<0.03
Zn	0.23	0.04

[a] 8-hr composite sample taken during first 8 hours of test 2.

TABLE 40. CARBON COLUMN PERFORMANCE DATA FOR PURGEABLE AND EXTRACTABLE ORGANICS[a]

Parameter	Concentration, mg/L Column 1, influent	 Column 2, effluent
Base/Neutral Extraction Fraction		
Trichloromethane	4.1	3.6
Benzene	5.5	5.4
Cyclohexene	12	10
Unknown	7.4	12
2-Cyclopenten-1-one, 3-methyl	2.8	–[b]
Acid Extraction Fraction		
Trichloromethane	4.5	5.5
Benzene	5.3	5.2
Cyclohexene	17	16
Phenols	2.5	

[a] 8-hr composite sample taken during first 8 hours of test 2.

[b] Blanks indicate compounds were below detection limit.

solids from the gas condensate. Assuming the following average operating conditions, the scheme would be expected to produce a final effluent with the composition presented in Table 41:

Steam stripper G/L ratio: 140 kg steam/m^3 water
(1.20 lb steam/gal water)

Activated sludge system HRT: 16 hours
Activated sludge system SRT: 32 days

GAC column contact time: 1,120 seconds

TABLE 41. OVERALL TREATMENT SCHEME PERFORMANCE DATA SUMMARY FOR CONVENTIONAL POLLUTANTS AND OTHER PARAMETERS

	Concentration, mg/L		
Parameter	Raw wastewater	Final effluent	Percent removal
NH_3-N	9,000	90	99
TKN	6,800	180	97
NO_3-N	1.1	0.4	64
Soluble COD	2,700	50	98
Soluble BOD_5	800	20	98
DOC	890	25	97
Phenols	120	0.02	>99
Sulfide	72	2	97
TSS	7	20	29
VSS	5	20	0
Alkalinity as $CaCO_3$ to pH:4.5	31,000	350	99
pH	8.5[a]	7.5[a]	-

[a] Standard pH units.

SECTION 5

QA/QC DATA SUMMARY

A summary of the quality assurance/quality control (QA/QC) data for all analyses conducted in this program is presented in Table 42. This summary has been prepared from the detailed QA/QC data. The data in Table 42 suggest minimal analytical discrepancies, but corrective actions were taken whenever such discrepancies occurred. These actions included review of the critical steps in the analytical methods with analytical technicians, discarding of unreliable data based on QA/QC problems, or outlier tests, and repeating the analyses until reliable data were obtained, as confirmed by satisfactory QA/QC results.

TABLE 42. QA/QC DATA SUMMARY FOR ALL ANALYSES

Analysis	Number	Type	Comments
TSS	169	Split	Percent relative difference = 0-23.4; average = 3.8%
VSS	158	Split	Percent relative difference = 0-30.1; average = 6.7%
TDS	2	Split	Percent relative difference = 0-1.8; average = 0.9%
Alkalinity	17	Split	Percent relative difference = 0-19.4; average = 2.4%
	12	Reference standards	Percent recovery = 99.5-110; average = 104.6%
NH_3-N	41	Split	Percent relative difference = 0-19.6; average = 3.0%
	16	Reference standards	Percent recovery = 84.6-111.5; average = 97.4%
TKN	6	Split	Percent relative difference = 0.4-7.7; average = 3.6%
	4	Reference standards	Percent recovery = 87-109; average = 95.8%
NO_3-N	3	Split	Percent relative difference = 10.5-11.8; average = 11.0%
COD	80	Split	Percent relative difference = 0.0-17.0; average = 3.1%
	58	Reference standards	Percent recovery = 81-121; average = 100.6%

(continued)

TABLE 42 (continued)

Analysis	Number	Type	Comments
DOC	40	Split	Percent relative difference = 0-18.9; average = 4.7%
	20	Reference standards	Percent recovery = 83.3-108.6; average = 98.4%
BOD_5	20	Split	Percent relative difference = 0-26.1; average = 6.5%
	8	Reference standards	Percent recovery = 88-97; average = 91.8%
Phenols	17	Split	Percent relative difference = 0.0-16.2; average = 7.7%
	6	Reference standards	Percent recovery = 87-122; average = 103%
Fluoride	2	Reference standards	Percent recovery = 65.2-139.1; average = 102.2%
Sulfide	1	Split	Percent relative difference = 8.3
Chloride	1	Reference standard	Percent recovery = 96
Cyanide	7	Split	Percent relative difference = 0-3.1; average = 1.5%
	5	Reference standards	Percent recovery = 89-101; average = 96.3%

(continued)

TABLE 42 (continued)

Analysis	Number	Type	Comments
O-PO_4	2	Split	Percent relative difference = 4.4-26.6; average = 15.5%
	1	Reference standard	Percent recovery = 98
Oil and grease	1	Split	Percent relative difference = 5.5
	1	Reference standard	Percent recovery = 84.6
Metals			
ICP method	3[a]	Split	Percent relative difference = 0-65; average = 8.8%
	2[a]	Reference standards	Percent recovery = 83-110; average = 101.7%
AA method	7	Split	Percent relative difference = 0-53; average = 7.9%
	8	Reference standards	Percent recovery = 63-127; average 92.2%
GC/MS Organics			
Chrysene-d_{12}	12	Spikes	Percent recovery = 86-166; average = 119%
Pyrene-d_{10}	12	Spikes	Percent recovery = 92-161; average = 116%
1,2-Dichlorobenzene-d_4	12	Spikes	Percent recovery = 43-92; average = 73%

(continued)

TABLE 42 (continued)

Analysis	Number	Type	Comments
DOC Fractionation			
Hydrophobic	3	Splits	Percent relative difference = 1-18.5; average = 7.7%
Hydrophilic	3	Splits	Percent relative difference = 0.5-15; average = 6.4%

[a] For each metal determined by ICP (inductively coupled plasma) spectroscopy.

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